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to unravel?

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across space

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Why they're so rare

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KEF Muo, What Hi-Fi?, September 2015

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WELCOME



YEARS AGO, I wrote an article about genius. My research led me, inevitably, to Einstein's brain. Removed at his death, it's been studied for decades by scientists looking for the key to creativity. I was told that the topography of his grey matter meant he was perfectly suited to both crunching through single-minded tasks and stepping far enough away from a problem to see it from a new perspective. The explanation made sense, but it never quite satisfied me.

Einstein didn't just make a connection that wasn't there. He saw the world anew. He realised space and time weren't fixed. Both were knitted together into an ethereal fabric that could be bent and warped, giving rise to gravity, among other phenomena. For the last century, his description of how the Universe works has held true, but this decade, it may finally start to unravel. Head to p38 for Marcus Chown's guide to the experiments testing the General Theory of Relativity to breaking point.

Closer to home, Bristol – *Focus*'s stomping ground – is getting kitted up with sensors, cameras and a supercomputer that will transform it into one of Europe's smartest cities. Take a tour with our very own Russell Deeks on p61. And finally, on p53, we ask leading experts in robotics, AI and employment whether one day we'll be free from the 9 to 5 to enjoy a life of leisure. Enjoy!

Daniel Bennett

Daniel Bennett, Acting Editor

PS Don't miss our Christmas issue, on sale 10 December 2015



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THIS MONTH WE...



...leapt from the top of a skyscraper at Canon Expo 2015 in Paris. Not really... it was a high-res photo. We also checked out the latest 8K displays, mixed reality and creative printing.

...caught up with Tim Peake in Cologne, ahead of his trip to the ISS. We even gave him a personalised copy of *Focus*! Don't miss our Christmas issue to read the full interview.



...paid a visit to the Hyundai Kia Festival of Ideas in Seoul. We got to see a bicycle that purifies water, a car that doubles up as a musical instrument and much more.

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APPEARING IN THIS ISSUE...



JV Chamary

JV has a PhD in evolutionary genetics, making him the perfect chap to investigate the science amateurs who are meddling with DNA. Find out what he discovered on p66.



Marcus Chown

Einstein's General Theory of Relativity marks its 100th birthday this month. On p38, astronomer and cosmologist Marcus investigates the theories that may unravel it.



Helen Scales

Helen is a marine biologist, writer and broadcaster. On p48, she reports on the lionfish that are decimating Caribbean reefs and uncovers an unusual control method...



Kevin Surace

Kevin is the CEO of Appvance. At one of his TED talks, he painted a picture of a world in which no-one has to work. Is it too good to be true? We chat to him on p53.



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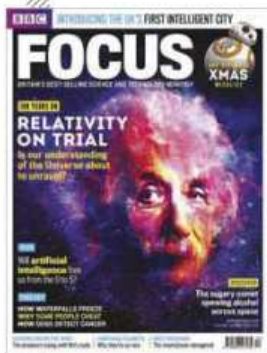


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On p36, **Carolyn Fry** digs into the world of botany and reveals the research that could transform food production

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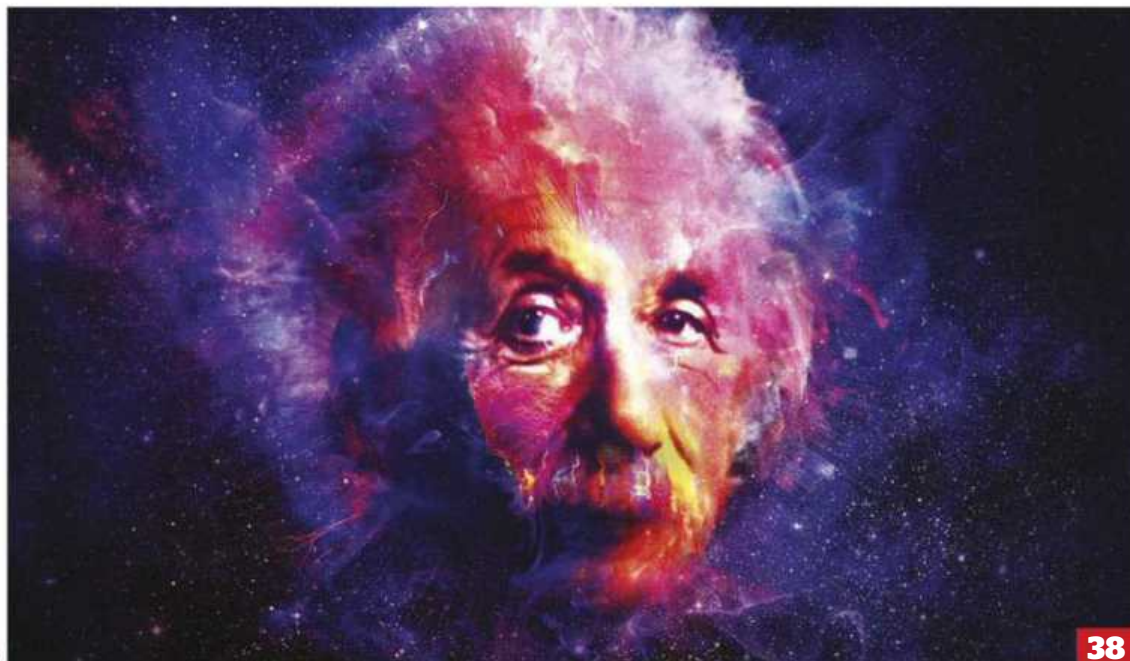
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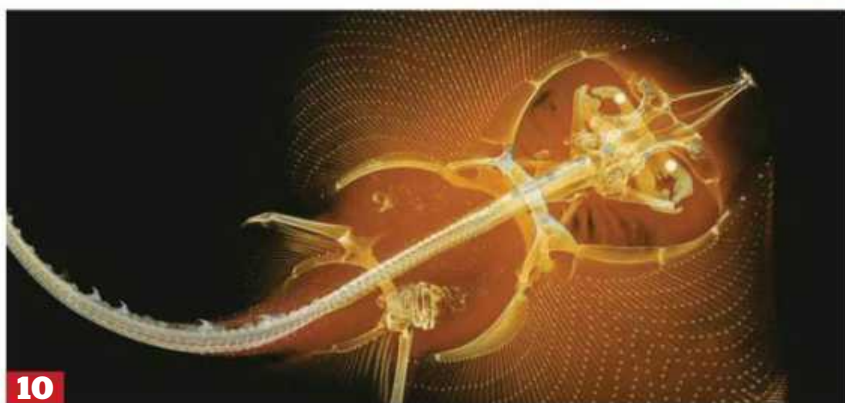
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Awe-inspiring images from the world of science

MegaPixel

Pearly whites

WHEN MOST ANIMALS bare their teeth, you're presented with a mouth filled with white gnashers. But only some of a thornback ray's teeth are present in its mouth – the vast majority of them are found on its skin.

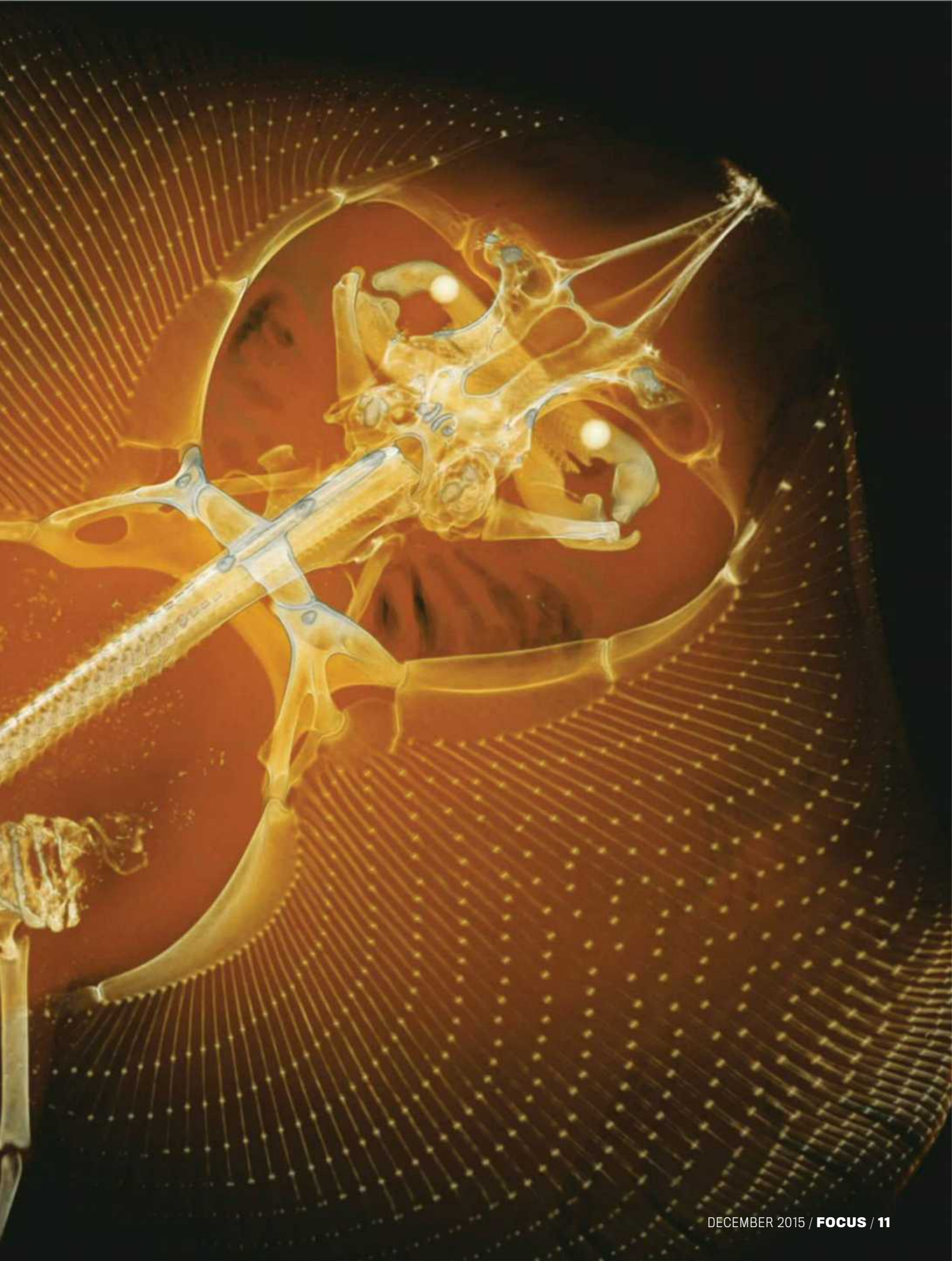
Thornback rays are typically found off the coasts of Europe and western Africa. Like sharks, the rays are covered in dermal denticles, or 'skin teeth', that enable them to swim more efficiently. It was research into the differences between the renewal mechanisms of dermal denticles on rays and sharks that led to the creation of this striking image, which was created with an X-ray micro-CT scan. The colours in the picture, taken by Dan Sykes, relate to the density of the

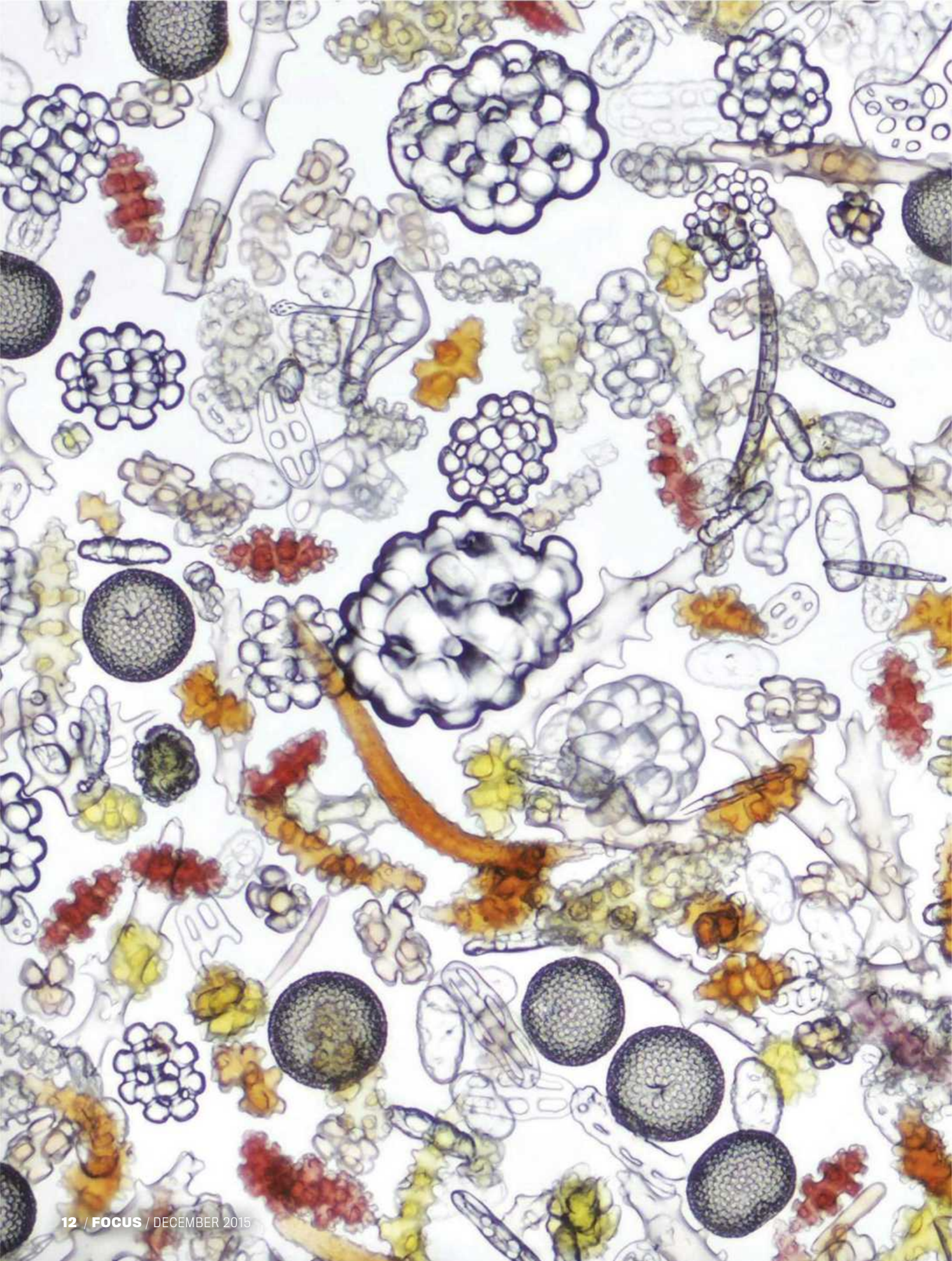
materials that make up the ray's body. High-density parts, such as the skeleton and teeth, show up white. Muscle and connective tissue, which are low density, appear orange.

The images over these six pages are part of the Royal Photographic Society's International Images for Science competition, sponsored by *BBC Focus*. You can see all the photographs at rps-science.org

PHOTO: DAN SYKES/RPS/REX FEATURES









MegaPixel

Sandy sweeties

THERE ARE CATACOMBS hidden under Paris that contain the skeletons of the deceased. While these tombs seem a world away from a tropical coastline, the two locations are more similar than you might think. On the beach, the fine, white sand between your toes is made up of the remains of tiny invertebrates. But when viewed through a microscope, the beauty of the sand is

brought to life. What looks like colourful pick-and-mix sweets are actually 'spicules'. These defensive calcium-based structures protect the soft bodies of marine organisms such as Gorgonian corals, sponges and sea cucumbers. This image was taken by award-winning wildlife photographer David Maitland.

PHOTO: DAVID MAITLAND/RPS/REX



MegaPixel

Breathtaking branches

NOPE, THIS ISN'T the root structure for some fearsome plant. This mass of black tendrils is part of a silk moth caterpillar's respiratory system, which differs dramatically from that of a mammal.

Rather than lungs, insects rely on a tracheal tree, which is a network of tubes that conveys oxygen around their bodies. Air is drawn in through spiracles - openings in an insect's exoskeleton - where it enters the tracheal tree. The branches extend throughout the insect's body, allowing the air to reach all its organs, tissues and cells. Hoops made

of chitin - the same material that forms an insect's hard exoskeleton - keep the tubes open so air can flow freely.

David Maitland created this image by using differential light microscopy to magnify the tracheal tree that he found on an Edwardian microscope slide. You can see this image and all the other finalists on display at the Edinburgh International Science Festival (26 March - 10 April 2016) and the Times Cheltenham Science Festival (7-12 June 2016).

PHOTO: DAVID MAITLAND/RPS/
REX FEATURES



Cooking

Made easier and quicker

What's the one thing in your life that always runs out? And the one thing you always wish you had more of? Time. As we go through life it seems we have less and less of this valuable resource. Occasionally it can seem like we have none to spare at all, especially when it comes to looking after a family.

Often it's mealtimes that gets pushed to the back of the agenda when trying to fit everything into your busy schedule. Convenience usually wins and this results in quick fixes such as; ready meals, takeaways and generally not very nutritious recipes. Delicious home-cooked food

shared around the family table can now be the norm thanks to your own personal kitchen assistants – the **Tefal Cook4Me** and **OptiGrill**.

Cook4Me

Super-fast and intelligent, the Cook4Me multi-cooker will ensure you spend less time cooking and more time enjoying delicious food with your family.

Cook4Me is interactive and smart in that it simplifies everyday cooking by guiding you, step-by-step, through every recipe in its pre-programmed library of 50 recipes (with 20 of these being suitable for vegetarians and 33 which cook in 15 minutes or less*).

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and temperature for each recipe
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*excluding preheating and browning time.



It also advises you on the quantity of each ingredient and automatically sets the respective cooking time, programme and temperature to match. This means, no matter what your skill in the kitchen, you will be helped every step of the way to ensure you prepare a delicious meal your whole family can enjoy.

OptiGrill

For those who struggle to keep track of timings when cooking the Tefal OptiGrill is a life-saver. Using the OptiGrill is like having a professional grill chef at home. Meat is cooked to your personal preference each time, whether rare, medium or well-done –

removing any worries about over or under-cooking.

There's no more need to keep opening the grill to check whether your food is done and no more cutting into the steak to see what colour it is.

Not just for steaks, the OptiGrill helps keep mealtimes varied and interesting with six automatic programmes with dedicated cooking cycles for different ingredients.

With time racing by, convenience seems to always win in our busy day-to-day lives but now thanks to some help from Tefal in the kitchen convenience and tasty, varied and nutritional family meals go hand-in-hand.

“Delicious home-cooked food shared around the family table can now be the norm thanks to your own personal kitchen assistants – the Tefal Cook4Me and OptiGrill.”

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Your opinions on science, technology and *BBC Focus Magazine*



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Letters may be edited for publication

NASA scientists celebrate
the first Moon landing in
1969. Or do they?

MESSAGE OF THE MONTH



What if..

I ENJOYED YOUR piece about conspiracy theories (November, p48). The trouble is, conspiracy theories can lead people down a blind alley with only two street signs to follow, 'fact' or 'fiction'. But a third option needs to be considered: both sides of the argument may turn out to be true.

For example, what if NASA *did* land on the Moon, but also worked up a contingency plan that mocked up a Moon landing in case of failure? As the Moon landing was successful there was no need for the back-up plan and the evidence was hastily buried. Now we have a scenario where NASA confidently defends conspiracy accusations with hard scientific facts, yet enough evidence exists of NASA's intended subterfuge to fuel conspiracy theories. Perhaps certain powers deliberately steer us into the 'fact or fiction' mentality in order to forever obfuscate the real truth.

Now that sounds like a conspiracy to me!

Henryk Kuzminski, Worcestershire

Write in and win!

The writer of next issue's Message of the Month wins a set of Urbanista Boston earphones, worth £59.99. With sound delivered to your ears via Bluetooth, you won't get tangled up in wires again, and they're also water-resistant, so a little rain won't hold you back! Available to buy from carphonewarehouse.com

Moon movements

Regarding your very interesting article on building a base on the Moon (November, p61). The list of Moon facts includes the subject of a letter I wrote to 'Q&A' a few months ago. Among other details you state that the Moon is moving away from earth at 3.8cm per year and also that it is 4.53 billion years old. My question, as yet unanswered, was why is it still visible, assuming the movement has been taking place for that immense length of time?

Some creationists claim that the moon could not possibly be more than a few thousand years old, otherwise it would long since have disappeared. Surely there must be some other explanation?

Hamish Neill, Suffolk

The answer is that the rate at which the Moon is moving away from us is increasing over time. So it's 3.8cm per year now, but it was less in the past. Back then, when it was closer, it felt a stronger gravitational pull from the Earth and so couldn't flee as fast.

- Colin Stuart

The makings of a Martian

The human colonisation of Mars will eventually happen. It seems a little less hostile an environment than the Moon, with water potentially more readily available. It is, of course considerably further away, with radio communication delay times of five to 21 minutes depending upon the orbits.

Early explorers will be kept busy simply trying to survive but with preparation the challenges are not insurmountable. A location close to the Martian equator offers maximum available sunlight and warmth, plus exposure for solar panels which I expect will be more efficient than those in use today. Landing within a modest size crater, with pre-delivered machinery and power plant close by, would offer advantages since it could provide initial shelter from radiation and the establishment of storage or living space.

Scenery might also prove an important consideration, as Mars is a desert planet. Locating your base in a side canyon of the vast Mariner Valley would offer

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63,204 (combined; Jul-Dec 2014)

Annual subscription rates (inc P&P):
 UK/BFPO £55.25; Europe & Eire Airmail
 £58.50; Rest of World Airmail £63.

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The Mariner Valley; a highly des res in Martian terms

interesting vistas to fuel the imagination of the colonist during whatever spare time he or she had during the day.

News and movies broadcast from Earth will be necessary for evenings, and to see out the occasional sandstorm blackout. A later phase, future biotech permitting, could be a transparent biodome, organically grown from newly delivered materials, possibly utilising basalt blocks or the wall of a small crater as foundations. Within the biodome, GM insects and plants would then establish the first Martian ecosystem.

All very fanciful – but then at one time, so was flight.

Jeff Clarke, Devon

A trip down Memory Lane

I read with great interest Alan Baddeley's piece on human memory (November, p16, subscribers only). The question 'Why do we forget so many things?' and the suggestion that we remember important things but not others, led me to wonder why we consider some things more important than others.

I suspect our interest in the experience or process plays a part here. At school I found the subject of history boring, but geography inspired me. I could easily

recall and draw maps, but not recall when a particular king was on the throne. So what brain function causes interest in a subject that another finds uninspiring?

Music was not mentioned in the article, but in my experience with learning to play the guitar I have found that when learning a new piece, all my effort of remembering goes into knowing which notes and chords to play, and where to form them on the fretboard. With practice this becomes less important as I visualise the phrases as a pattern or shape rather than individual notes. Could this be part of the consolidation of the neurochemical trace left by the learning experience, and the result of the hippocampus transferring information to other parts of the brain?

I did have another point to make, but can't recall it at the moment, so it can't have been very important...

Ron Hayward, London

Making a meal of it

In 'Putting research to the test' (October, p31), Robert Matthews suggests that students should do exactly that – subject the published results of professional scientists to further scrutiny.

Undergraduates in Glasgow University's Chemistry Department, in 1971, were indeed asked to repeat procedures described in a peer-reviewed journal. We found that the original authors' conclusion was, as Glaswegians say, 'mince'. Our lecturer agreed. However we were never told why this erroneous paper remained, leather-bound, on our library shelves.

Presumably it takes a degree of moral courage to challenge the findings of establishment figures, especially if they can influence your future career.

John Samson, Edinburgh



Patterns, such as a chord sequence on a guitar, play a role in how we remember things



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DISCOVERIES

News and views from the world of science

EDITED BY
JASON GOODYER

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PLASTIC UNFANTASTIC

We need the oceans, so why are we letting them become a plastic soup?



p30

SUGARY COMET

It's spewing out alcohol! Christmas has come early...

p35



NEW SPECIES FOUND

Weird creatures, including a blue-eyed frog and a walking fish

THE BIG STORY

MOST EARTH-LIKE PLANETS ARE YET TO BE BORN



According to data from the Hubble Space Telescope and Kepler, Earth may be one of the earliest habitable planets in existence

THE EARTH MAY be one of the earliest habitable planets ever to form, researchers from the Space Telescope Science Institute have found.

Scientists surveying data collected by NASA's Hubble Space Telescope and the planet-hunting Kepler space observatory have found that when our Solar System



The Universe may continue to pump out planets for billions of years

PHOTO: NASA

The Kepler mission is looking for planets around other stars in the Milky Way



GOOD MONTH/ BAD MONTH

It's been good for:

WEIGHTLIFTERS

PUMPING IRON TWICE a week may help keep your brain young. A team at the University of British Columbia has found that those who worked out with weights had less age-related brain shrinkage than their peers.

THE FOLLICLY CHALLENGED

IF YOU HANKER after the days when you had a head of luscious hair, you may be in luck. A Columbia University team has found that rapid hair growth can be triggered in mice by giving them drugs that inhibit certain enzymes within their hair follicles.



It's been bad for:

DOTING FATHERS

ANY FATHER IS likely to beam with joy upon hearing their baby blurt out 'dada' for the first time. But their pride is misplaced, a study from the University of Missouri has found. The babies aren't calling for their fathers but are instead listening to the sound of their own voice.

MEAT LOVERS

NEXT TIME YOU are reaching for that bacon butty or sausage bap you might want to think twice. A report released by the World Health Organization claims that eating just 50g of processed meat a day, less than one average sausage, can increase the chance of developing colorectal cancer by 18 per cent. However, the overall risk of developing cancer due to the consumption of processed meat still remains small, they said.



→ came into being 4.6 billion years ago, only 8 per cent of the habitable Earth-like planets that will ever form existed.

The overwhelming majority – a whopping 92 per cent – of the planets are still yet to be born and will not appear until long after our Sun burns itself out in around six billion years' time.

"Our main motivation was understanding the Earth's place in the context of the rest of the Universe," said study author Dr Peter Behroozi. "Compared to all the planets that will ever form in the Universe, the Earth is actually quite early."

For a planet to be considered habitable, it has to orbit its parent star at a distance that could allow liquid water to exist on the surface – not so close that it boils away, and not so far away that it freezes. Based on data from Kepler's planet survey, the researchers predict there are currently around one billion Earth-sized planets in the Milky Way and 100 trillion in the observable Universe.

Data from the Hubble Space Telescope shows that 10 billion years ago the Universe was making stars at a much faster rate than it is now. However, only a small proportion of hydrogen and helium gas, the elements needed to form a star, was used.

Although the formation rate is much slower today, the sheer volume of leftover gas means that the Universe will continue to pump out stars and planets for hundreds of billions of years.

"There is enough remaining material after the Big Bang to produce even more planets in the future, in the Milky Way and beyond," added co-investigator Dr Molly Peeples.

The Universe's last star is not expected to burn out for another 100 trillion years, providing enough time for countless numbers of Earth-like planets to form in habitable zones. This is perhaps bad news for those hoping to come into contact with alien life forms, but it does offer us one advantage: we are able to use powerful telescopes such as the Hubble Space Telescope to peer deep into the Universe allowing us to track its birth all the way back to the Big Bang.

We're lucky to live at this point in the Universe's history. Observational evidence for the Big Bang and cosmic evolution – encoded in light and other electromagnetic radiation – will be all but erased in a trillion years due to the runaway expansion of the Universe. This will make it incredibly difficult for far-future civilisations to figure out how the Universe began and evolved.

TIMELINE

A history of exoplanet research

1992

Astronomers Aleksander Wolszczan and Dale Frail track down PSR1257+12b, which is the first planet ever discovered outside the Solar System.

1999

David Charbonneau (right) and Greg Henry independently observe HD209458 b, the first transiting exoplanet. It is the first exoplanet known to have an atmosphere.



2001

Astronomers from Geneva University find HD28185 b, the first exoplanet found to be in the so-called habitable zone around a star where liquid water can exist.

2009

NASA's Kepler mission launches to survey a region of the Milky Way with the goal of discovering Earth-like planets orbiting other stars.



The price of plastic bags

DAVID SHUKMAN
The science that matters

AT A RESORT in Turkey, the beach closest to our hotel was spotless but a neighbouring stretch of sand was almost covered with pieces of plastic. Bags, bottles, ropes and other items lay heaped on the shoreline and turned a potentially beautiful spot into a dump.

Just offshore, I filmed more plastic bobbing on the swell. The experience was pretty shocking because – like an iceberg – the majority of waste drifts unseen below the waves. I used the shots in a report on the BBC's *News at Six* marking the recent introduction of a 5p charge for bags in England. The editors were appalled at the scene.

The latest estimate is that some eight million tonnes of plastic are added to the oceans every year and that creates two big threats. For a start, the stuff accumulates. Plastic has become central to our lives because it is so durable, but this means that much of it lasts. The second problem is that flimsy pieces of plastic, such as bags, get broken up into millions of tiny fragments and what happens to them is now the subject of urgent research.

Studies at Plymouth Marine Laboratory and the University of Exeter have shown that so-called microplastics are ingested by creatures at the bottom of



Plastic waste at Labuan Bajo in eastern Indonesia

the marine food chain. Research suggests that a person eating an average amount of seafood would consume about 11,000 plastic particles every year. That may be harmful – or not. Other toxins in seafood, such as heavy metals, may be far more threatening. We cannot be sure.

And this brings to me to some good news. When I first reported on the threat of plastic waste seven years ago, it seemed

to land as a bombshell for many people. Now there's far greater awareness of the potential impact of marine plastic.

And there's also been a huge increase in scientific engagement. Plastic waste is a menace that not only concerns oceanographers and conservationists but also biologists, chemists and toxicologists. If we're to understand the true scale

of the threat to marine life, and ultimately to us, we need a sustained and concerted research effort.

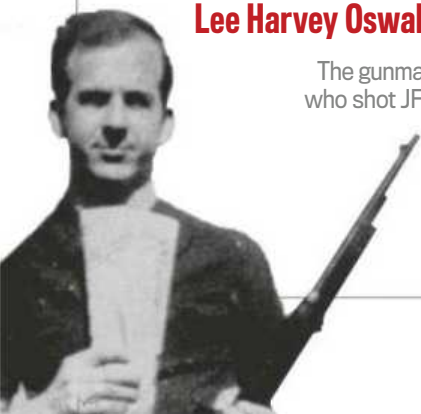
In the meantime, the priority has to be to try to stop yet more plastic getting into the oceans in the first place. Just a thought next time you're offered a bag.

DAVID SHUKMAN is the BBC's Science Editor. @davidshukmanbbc

WHO'S IN THE NEWS?

Lee Harvey Oswald

The gunman who shot JFK



Hang on. Didn't he die in 1963?

He did. But conspiracy theories surrounding the assassination of President John F Kennedy have proved more difficult to kill off.

So are there any new developments?

There are. Wearers of tinfoil hats have long claimed that a famous black and white photograph of Oswald holding

a 6.5mm Carcano rifle, the same model used to shoot Kennedy, was faked. They cite inconsistencies in the shot's shadows and the fact that he looks to be off-balance. Oswald himself also claimed that the picture was a fake.

What's the verdict?

Computer scientists at New Hampshire's Dartmouth

University used 3D modelling techniques to accurately recreate and analyse the photo. They found that although Oswald was standing at an unusual angle in the picture, his posture would still have been stable. The lighting and shadows were also found to be consistent with the light source. To find out more, listen to an *In Short* clip at bbc.in/1GRZsPP

1 MINUTE EXPERT

Meson f0(1710)



What's that? A new first-person shooter, perhaps?

Way off. It's an exotic particle proposed as a candidate for the elusive 'glueball' by scientists at Vienna University of Technology.



So what's a glueball?

It's a particle made up entirely of gluons – elementary particles that help to bind quarks together to form protons and neutrons. Its existence was first proposed by physicists Murray Gell-Mann and Harald Fritzsch in 1972.



Okay. What makes them so elusive?

Glueballs are so unstable that they can only be detected indirectly by searching for evidence of their decay patterns. This means that researchers must look for the signature particle trails they leave behind as they break down. The team has proposed a mechanism for this decay process.



So now they have found them, we can break out the champagne, right?

Not just yet. While there is strong evidence that the team have got their sums right, the theory is going to be tested further in experiments carried out by the TOTEM and LHCb detectors at CERN's Large Hadron Collider in the coming months.



A glueball is made up of gluons



One day, could drugs offer all the benefits of pounding the pavements?

MEDICINE

Could we create 'exercise in a bottle'?

WE ALL KNOW that working out is good for us but sometimes the sofa and a bag of crisps are just too inviting.

A team at the University of Sydney has found that drugs could potentially be created that mimic the effects of exercise. "Exercise is the most powerful therapy for many human diseases, including Type 2 diabetes, cardiovascular disease and neurological disorders," explained research leader Prof David James. "However,

for many people, exercise isn't a viable treatment option. This means it's essential we find ways of developing drugs that mimic the benefits of exercise."

The researchers analysed muscle biopsies from four untrained, healthy males following 10 minutes of high intensity exercise. They found that activity triggered more than 1,000 molecular changes within the muscle.

Most traditional drugs target individual molecules,

but the exercise blueprint shows that for any drug to mimic exercise it will need to target multiple molecules at the same time.

"We believe this is the key to unlocking the riddle of drug treatments to mimic exercise," James said. "Our data clearly show the complexity of the response: it is not one thing, but rather the drug will have to target multiple things. Our research has provided the roadmap to figure this out."

NEUROSCIENCE

Dream on... and off... and on...

SWEET DREAMS COULD be a mere flip of a switch away. A team at UC Berkeley has devised a method of sending mice into REM sleep in seconds.

The scientists inserted an 'optogenetic switch' into group of nerve cells in the medulla, a part of the brain that regulates functions such as breathing, heart rate and blood pressure. They then shone lasers at targeted areas of the brain to activate and deactivate it.

REM (rapid eye movement) sleep is the dream state characterised by activation of the cortex, an area of the brain connected to memory, thought and consciousness, and paralysis of the skeletal muscles.

"People used to think that this region of the medulla

was only involved in the paralysis of skeletal muscles during REM sleep," said lead author Yang Dan. "What we showed is that these neurones triggered all aspects of REM sleep, including muscle paralysis and the typical cortical activation that makes the brain look more awake than in non-REM sleep."

The discovery will help researchers understand the complex process of sleep and dreaming in the brain, and could lead to new therapies, the researchers said.

"Many psychiatric disorders, especially mood disorders, are

correlated with changes in REM sleep, and some widely used drugs affect REM sleep, so it seems to be a sensitive indicator of mental and emotional health," said researcher Franz Weber.



All tucked out from experiments

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10 DISCOVERIES THAT WILL SHAPE THE FUTURE

BY GRAHAM SOUTHRN

10 Migraine breakthrough

ABNORMAL ACTIVATION of a cluster of brain cells called the 'trigemino-vascular system' is believed to be responsible for causing migraines. The cluster relays sensory information, including pain signals, but which part of the nervous system triggered it was unknown. Now, an international team has treated migraines in rats by targeting cells deep inside the brain. The scientists used a compound to block PAC1 – a receptor protein – but so far it has only been applied directly to the brain, rather than intravenously.

Abnormal activation of a cluster of neurones may cause migraines

PHOTO: C BICKEL/SCIENCE TRANSLATIONAL MEDICINE, ROB FELT, VIKRUPESHWAR SITARAMAN, FLORIDA ATLANTIC UNIVERSITY, TRILITE, RUVID, AMY BETZ/KANSAS STATE UNIVERSITY, MINORU TAKASATO, MARCO TRIPODI

9 Self-destructing circuit

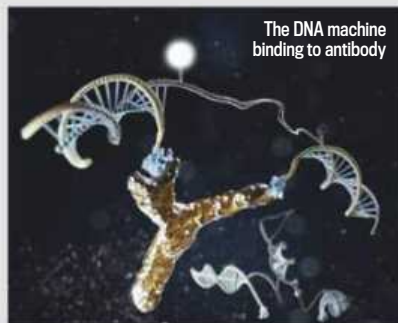
JAMES BOND'S GADGET supplier Q would be proud of this: an electrical circuit that disappears after one day, leaving no trace of its original purpose. Georgia Institute of Technology designed it by depositing carbon atoms on graphene – the 'miracle material' that's also a form of carbon. The atoms initially form a circuit but gradually move out of position. The speed of this change depends on the temperature and specially designed structures on the surface. **In addition to espionage there are medical applications: different patterns of atoms could trigger the release of drugs into a patient's bloodstream.**



Andrei Fedorov created the Bond-like circuit

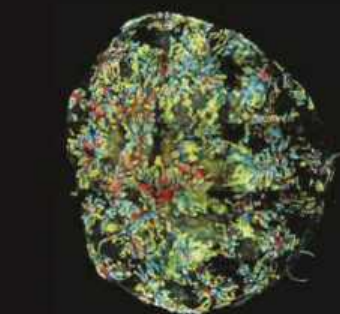
8 HIV detector

A FAST, CHEAP way of diagnosing infectious and autoimmune diseases such as HIV and rheumatoid arthritis has been developed at the University of Montreal. A 'machine' made of DNA can recognise a specific antibody – binding to it and creating a signal by generating light – within five minutes.



The DNA machine binding to antibody

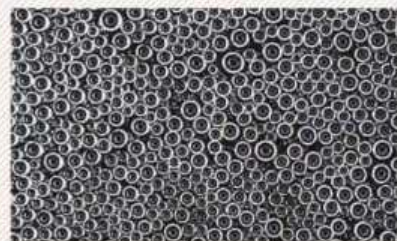
7 Lab-grown kidney cells



LAB-GROWN KIDNEYS suitable for transplants are some way off. But scientists at Murdoch Children's Research Institute have grown a kidney-like structure from stem cells. It could be used for testing drugs, researching diseases and supplying kidney cells for medical treatments.

6 Anti-frost surface

FROST PLAYS HAVOC with travel plans, covering your car windows and delaying flights. But now a surface has been created by engineers at Kansas State University that prevents frost forming at temperatures down to -6°C. It's 'biphilic', repelling water in some areas and attracting it in others, which delays the freezing of the droplets.

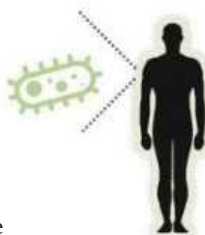


Droplets forming on a biphilic surface at -4°C

5 Microbe 'fingerprints'

CRIMES COULD be identified from microbes in the air.

We all have bacteria living on us, but the combination varies. University of Oregon scientists told 11 people apart simply by sampling the air around them.



Your bacterial 'aura' is unique

4 Robotic finger

A 3D-PRINTED robotic finger that looks and feels like a human appendage could be the future of prosthetics. It is made of shape memory alloy (SMA) that flexes and extends when it's heated and cooled by an electric current.



This finger could revolutionise prosthetics

2 Self-repairing material

IMAGINE HOW USEFUL a self-repairing material would be. It could be used in parts for cars, planes and spacecraft to help prevent catastrophic failures, and medical implants that break inside a human body could simply heal themselves. Such a material, which is capable of rejoining itself in less than 15 seconds if cut with scissors, has now been developed. Scientists at the University of Alicante say that the flexible, transparent resin is even able to heal itself underwater, retaining its original shape in the process.



Very good, but give us a call when you've made an entire dinner set from the stuff



You're gonna need a bigger screen...

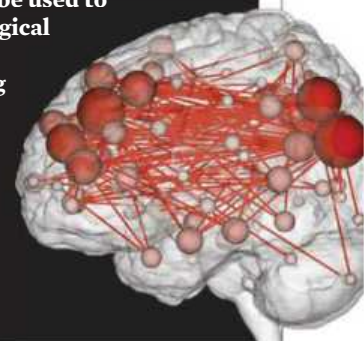
3 Three-dimensional billboard

3D IS BACK again. At Vienna University of Technology, researchers have perfected a 3D display requiring no glasses. Its pixels, dubbed 'Trixels', combine red, green and blue lasers and moveable micro mirrors. The image changes as the mirrors sweep from left to right across your field of view,

creating a 3D picture by giving each eye a different perspective. **The system is capable of playing 3D movies or serving up eye-catching adverts on gigantic billboards.** Its makers say the technology is ready for commercial partners to take it forward.

1 Personalised education

EVERYONE'S BRAIN CELLS – neurones – form a unique pattern of connections, according to research by Yale scientists. They identified 126 individuals from brain scans taken as they performed a variety of tasks, producing a 'fingerprint' called a connectivity profile. The profiles could be used to predict how logical you are, how good at solving problems, and could even be used to tailor educational courses.



SPACE

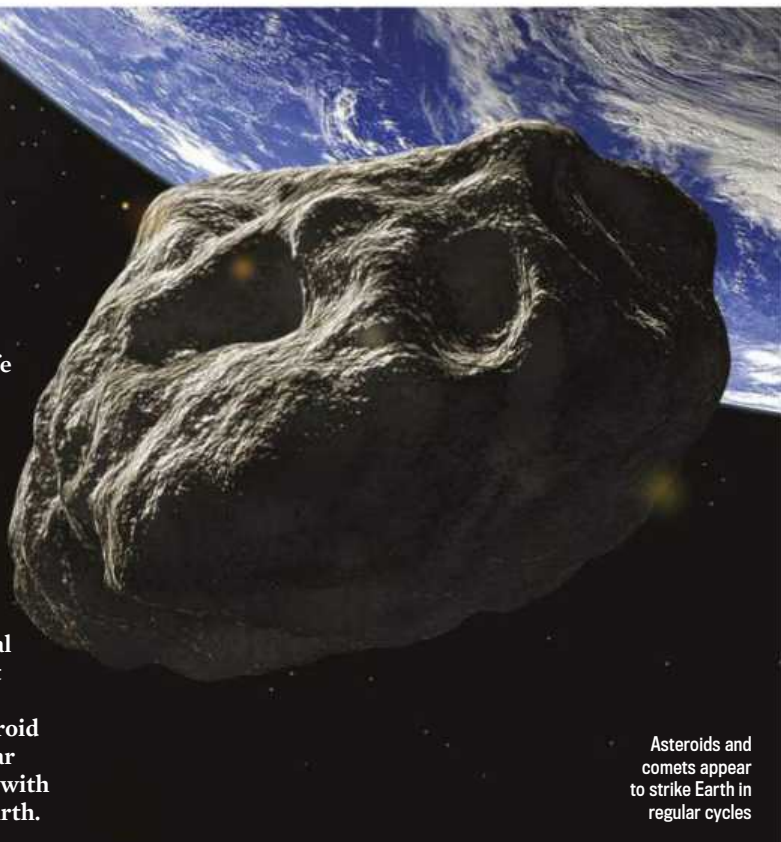
Do asteroids cause mass extinctions?

YIKES! IT SEEMS comet and asteroid showers may be causing mass extinctions on Earth in an alarmingly regular cycle. But before you start to panic, the good news is that another one isn't due for around 14 million years.

Through studying the age and regularity of impact craters over the last 260 million years, researchers in the USA have discovered a strong correlation between mass extinction events and an increased number of asteroid strikes. What's more, they found the two events occur in regular intervals of around 26 million years.

"This cosmic cycle of death and destruction has without a doubt affected the history of life on our planet," said New York University's Dr Michael Rampino.

The cycle has been linked to the periodic motion of the Sun and planets through the dense mid-plane region of the Milky Way. It is thought that gravitational effects of the Oort comet cloud that surrounds the Sun may trigger asteroid showers in the inner Solar System during this time, with some of them striking Earth.



Asteroids and comets appear to strike Earth in regular cycles

PHOTO: GETTY



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ROBERT MATTHEWS

THE COST OF CHRISTMAS

Don't be tricked by marketing plays this holiday

DON'T YOU JUST love Christmas? Me neither. Actually, that's not quite true. I like the social side of it – seeing friends and relatives, enjoying carol concerts and big feeds. What I object to is the sense of being psychologically manipulated by big business.

Economists have been saying for years that we'd all be better off if we could rid ourselves of the emotional blackmail of gift buying. Over 20 years ago, Yale University economist Joel Waldfogel coined the term 'deadweight loss of Christmas' to describe the orgy of wealth-destruction that breaks out during the holiday season.

Over the next few weeks, we'll be splurging around £15bn preparing for the festivities, with the bulk of it – around £10bn – going on pressies.

That's great for big business. But according to Waldfogel, as much as 30 per cent of that £10bn is wasted on gifts that people give but the recipients don't want. In other words, the 'deadweight loss' of Christmas could be as high as £3bn.

In these financially straitened times, can we really afford to throw money away on that scale?

Some will see this as a classic case study in 'the dismal science' of economics. After all, the money isn't wasted – it's the thought that counts.

Certainly the retail trade puts a lot of thought into Christmas. They even have their own branch of the dismal science to help them. It's called behavioural economics and it's scarily powerful.

One of the highlights of my year was spending two days at BX2015, an international gathering of the behavioural economics community. The cast included American

economist Richard Thaler, a pioneer of 'nudge theory'. This identifies ways of getting people to change their behaviour by subtly tilting their options, rather than restricting them.

The UK arguably leads the world in this, the Cabinet Office having set up a 'Nudge Unit' – officially the Behavioural Insights Team – in 2010. Among its many successes have been dramatic improvements in recovery of taxes, simply by telling late payers how their money is vital for public services.

There were plenty of government officials at BX2015 looking to learn what behavioural economics can do for them. But the retail sector has been on to this kind of stuff far longer. There were probably Neanderthals sitting outside caves saying 'big sale – final reductions' during the Ice Age.

"There were probably Neanderthals sitting outside caves saying 'big sale – final reductions' during the Ice Age"



Overspending at Christmas is as hard to resist as that last mince pie

Their high-street counterparts routinely exploit this so-called 'scarcity principle', and it's one of the key nudge factors identified by another of the stars of BX2015, social psychologist Robert Cialdini of Arizona State University. The threat of missing out bounces us into doing – and buying – all sorts of stupid things.

Another is reciprocity – put simply, giving something to get something. This is powerful and is a key driver of Yuletide wealth destruction. We feel awful when we break the reciprocity principle, so we get bounced into buying presents on the off chance the other person will.

There are glimmerings of hope. People send far fewer Christmas cards than they used to: apparently oldies resent the soaring cost and kids prefer social media. But charities are suffering from the loss of revenue.

It's time we all pushed back against the commercially driven nudging of Christmas. Instead of buying gifts, maybe we should tell everyone to make donations to charities on our behalf instead. Then we'd save ourselves a fortune, a lot of hassle and any worry about not giving others what they really want. ■

ROBERT MATTHEWS is Visiting Professor in Science at Aston University, Birmingham

SPACE

Comet found to be spewing out alcohol



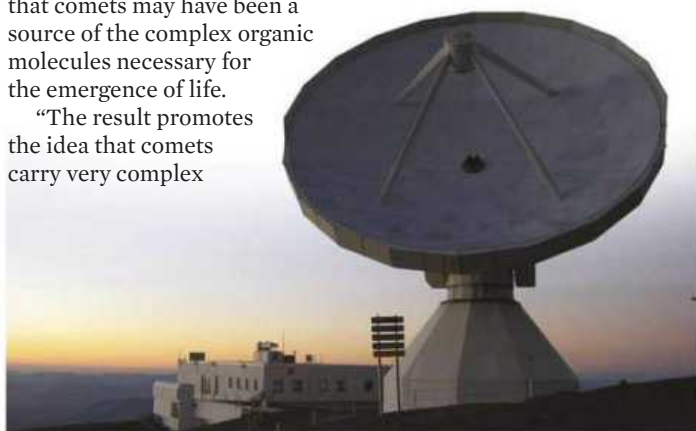
IT GIVES A whole new meaning to the phrase 'booze cruise': researchers at NASA's Goddard Space Flight Center have found that Comet Lovejoy is spraying vast amounts of alcohol into the cosmos.

The team found 21 organic molecules on the comet in total, including ethyl alcohol and glycolaldehyde, a simple sugar. Lovejoy was pumping out up to 500 bottles of wine's worth of alcohol per second. This is the first time ethyl alcohol has been observed in a comet and the discovery is further evidence that comets may have been a source of the complex organic molecules necessary for the emergence of life.

"The result promotes the idea that comets carry very complex

chemistry," said researcher Stefanie Milam. "During the Late Heavy Bombardment 3.8 billion years ago, when many comets and asteroids were blasting into Earth, life didn't have to start with just simple molecules like water, carbon monoxide, and nitrogen.

"We're finding molecules with multiple carbon atoms. So now you can see where sugars start forming, as well as more complex organics such as amino acids, the building blocks of proteins, or nucleobases, the building blocks of DNA," she added.



BIOLOGY

Cheap 'mini-brains' could reduce animal testing

IT'S GOOD NEWS for the scarecrow from *The Wizard Of Oz*: researchers at Brown University have developed a method of growing functioning 'mini-brains'.

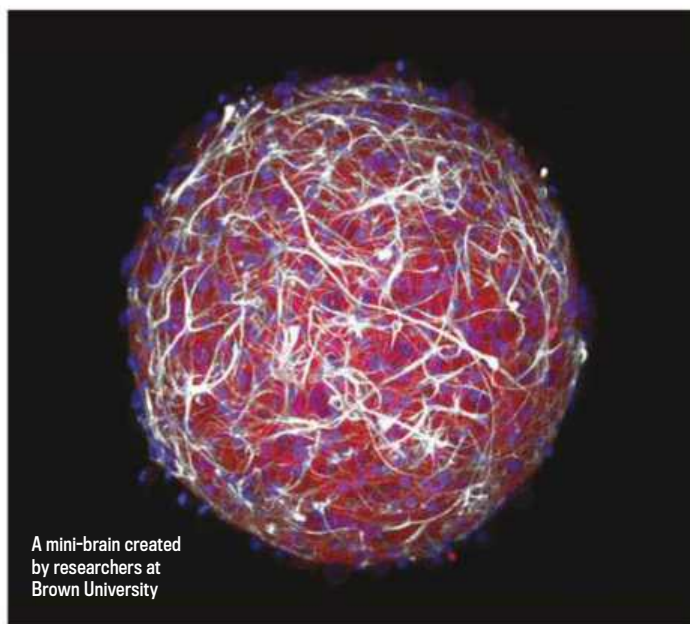
The little brain balls can't think like real grey matter, but they do produce electrical signals and form their own neural connections, making them a suitable replacement for animals in drug testing.

To produce the brains, the team isolated cells from a small sample of living tissue taken from a rodent and placed them into tiny spherical moulds about 3mm across. The tissue began

growing within 24 hours and formed complex 3D neural networks in two to three weeks. They can live for upwards of one month.

Thousands of the tiny organoids can be made from a small tissue sample, and they cost just 16p each to produce.

"We think of this as a way to have a better in vitro [in the lab] model that can maybe reduce animal use," said researcher Molly Boutin. "A lot of the work that's done right now is in two-dimensional culture, but this is an alternative that is much more relevant to the in vivo [real life] scenario."



A mini-brain created by researchers at Brown University

THEY DID WHAT?!

Cadaver arms used to 'throw punches'

What did they do?

University of Utah researchers attached the arms of male cadavers to a pendulum and swung them into a force-

detecting pad to emulate the throwing of a punch.

Why did they do that?

They wanted to test the theory that the human hand evolved to enable males to engage in fights over women. The idea comes from the fact that we have shorter palms and longer, stronger, more flexible thumbs compared to other apes.

What did they find?

After testing hundreds of punches, they found that humans are able to strike with double the force when using a clenched fist rather than an open-handed strike. The hand could have evolved due to improvements in manual dexterity while also providing a benefit for those engaging in fisticuffs.



Human hand: evolved for fighting?



HELEN CZERSKI

MAPPING WITH MAGNETS

A simple compass reveals a whole new world

YOU'D HAVE THOUGHT I'd know my own home, but I discovered this week that there's far more to it than I'd appreciated. I bought myself a nice, sensitive navigational compass, sadly not one with a shiny brass case and engravings of ships, but still a compass in the original style with a quivering needle and a bold arrow for north. I spent a while doing pirouettes and being impressed that the needle could keep up, then I put it down next to a metal ruler on my desk. The needle whizzed round and pointed at the ruler. It had never occurred to me that the ruler might have its own magnetic field. The compass clearly had far more than navigation to offer. Twenty minutes of wandering round my flat, watching as the needle mapped out what I couldn't see, changed my view of where I live.

When you think about it, it's pretty cool that compasses work at all. The Earth has its own magnetic field that pokes out of the magnetic North Pole (which isn't in quite the same place as the geographic North Pole) and reconnects with the planet at the South Pole. It's a fairly weedy magnetic field – even a standard fridge magnet is 100 times stronger. But it's always there, wherever you are. If you put two bar magnets next to each other, their north poles will fly apart and they'll spin around until their north and south ends touch. And if you put a bar magnet on the surface of the Earth, it will also spin to align itself if it's free to move. That's why the needle on my compass is so delicate – there's very little friction or inertia to stop it moving. Every bar magnet will feel the tug of the planet – this needle is only special because it can respond very quickly.

Mostly, the magnetic field pushes the needle to point north. But my steel kitchen knives all re-shape their local magnetic field, adding a loopy pattern on top of the Earth's magnetic background. The needle spins around each knife, showing that something magnetised it in the past and it's never lost that magnetism. The pattern from the iron saucepans is all over the place, and it's the same for my tablet computer, battery-powered clocks, plug sockets, the television and my keys. A bit more investigation shows that the metal ruler actually has quite a complicated magnetic field – it changes direction every few centimetres. But magnetic field strength drops off very quickly with



There are magnetic patterns all around your house, and you just need a compass to find them

“Now, when I look around my flat, I imagine delicate magnetic field lines running through it, and through me”

distance, so each object only adds small twirls and twists to the overall pattern. My neodymium magnets in the corner are the magnetic giants in the room, their influence extending out for 30cm or so from the bookcase.

And this is just the fixed magnetic patterns. The alternating current running through the wires in the walls is generating its own magnetic pattern, but since it's changing direction 50 times each second, my compass can't move fast enough to show it. The push of a changing current like that on a permanent magnet can make the magnet spin as it tries to keep up – that's all an electric motor is.

So now, when I look around my flat, I imagine delicate magnetic field lines running through it, and through me. Their straight flow is being sculpted into whorls by temporarily magnetised iron and by electric components and circuits. None of it is harmful to us. But the most amazing thing of all is the comparison between this minuscule compass needle, and the vast planetary-scale magnet that it detects. It's such a simple way of mapping out our magnetic world! ■

DR HELEN CZERSKI is a physicist, oceanographer and BBC science presenter whose most recent series was *Super Senses*



PATENTLY OBVIOUS with James Lloyd

Inventions about to change your world

Fragrant flavours

DRINKING WATER MIGHT be better for us than fruit juice or fizzy pop, but sometimes our taste buds yearn for something with a little more flavour. The Right Cup is a scented vessel that tricks your brain into thinking you're drinking flavoured water. The fruity scent – choose from lemon-lime, orange, mixed berry or apple – is added to the plastic cup during manufacturing, and your brain mistakes the scent for flavour. This approach means you're not consuming any sugars or chemical preservatives.

Patent pending

Calming computers

THE NEXT TIME you're sitting at your computer, quietly seething as it does exactly what you didn't tell it to do, let Bill Gates sort it out. Microsoft is patenting a system that detects when you're stressed out and helps to calm you down. It might detect your ire by measuring the pressure you exert on your keyboard, listening for expletives, or recognising the tell-tale features of an angry face. It would then try to soothe you – perhaps adjusting your room's lighting, or telling you it's time to take a walk. And breathe...

Patent pending

It's a dog's life

WE'VE BEEN LIVING with man's best friend for thousands of years, but we still struggle to understand our canine friends. We often assume that a dog's wagging tail is a sign of unbridled excitement ("yay, walkies!"), but it can also signal fear ("keep that Rottweiler away from me!") or aggression ("this is my manor, sunshine, so do one").

Now, New York company DogStar has created a device that it hopes will translate your dog's emotions. TailTalk is a small, unobtrusive sensor that fits around the dog's tail, converting its wagging into a happiness rating that's displayed on the accompanying app.

The device is based on sound science, with research showing that dogs tend to wag towards the right when experiencing positive emotions, and towards the left when feeling anxious or upset. The app will use this information to create an emotional diary for your dog, revealing exactly what makes Rover rejoice or Fido feel frightened.

Provisional patents issued



Can a wearable device reveal your dog's mood?

NEUROSCIENCE

Remote-controlled roaches

HERE'S SOMETHING

that's unlikely to make it to the top of many Christmas lists: cockroaches that can be controlled with a joystick.

A team at Case Western Reserve University inserted tiny electrodes into the part of the insects' brains that respond to antennal and visual stimuli. They then recorded the neuronal activity and filmed the insects' movements. By making statistical links between movements and spikes in neuronal activity, they were able to figure out the signals associated with the insects walking at different speeds and changing direction.

They then passed electrical currents through these same electrodes, turning the insects into remote controlled roaches. Similar experiments in the past worked by stimulating the

insects' antennae, rather than neurones inside the brain.

"It's like a joystick on the animal," said researcher Joshua Martin. "We can control its direction and alter its speed."

The team believes that similar processes may exist in other animals. "It is highly likely that descending motor control such as this also resides in all legged animals, including us," lead author Roy Ritzmann said. "So this kind of study, with the technical advantages that insects afford researchers, can help us to understand how movement is controlled in complex environments."

The cockroach's control system could also prove to be a useful model for building self-driving cars and robots that can manoeuvre around obstacles on their own, or for controlling drones, the researchers said.

Experiments on cockroaches may help us learn more about motor function in all animals' brains





STEPHEN BAXTER

COSMIC CLINIC

Staying healthy in space won't be easy for future Martians

AUTUMN SAW THE release of *The Martian*, in which a stranded astronaut must improvise everything needed for his own survival. Today, agencies like the European Space Agency have offices dedicated to space medicine, and the International Space Station is serving as a test-bed for medical techniques in space.

Before the first manned flights, there was speculation that humans might not be able to withstand space travel. In 1959, US psychiatrists theorised that a detachment from 'Mother Earth' might lead to suicidal 'separation anxiety'.

In fact, the first astronauts returned safely from their short hops into space. But longer missions, such as the two-week lunar journeys of the Apollo astronauts, revealed deeper dangers. Astronauts lose bone mass in zero gravity; in 2009, the calcium washed out of astronauts' bodies actually gugged up a urine recycler on the ISS. Sleep deficiency is common in an environment with no up or down, no night or day. Zero gravity even affects the shape of the human heart, causing it to become more spherical, which possibly causes problems with its efficiency.

And there have indeed been some psychological problems. During the American Skylab 4 mission, the crew got so mad at mission control that they cut radio contact for a day. Long periods of isolation and confinement must account for some of this, but there is some evidence that an altered blood flow in the brain can lead to an impairment of mental function.

Deep space missions carry additional hazards. Earth's magnetic field shields people on the ground and in Earth-orbiting space stations from radiation from the Sun and more remote cosmic sources, but NASA estimates that a year-long flyby mission to Mars would expose astronauts to more than an acceptable lifetime dose of radiation. Solutions may include better shielding, medication and even the genetic treatment of the crew for radiation resistance.

Medical emergencies are a hazard in deep space. An ISS astronaut could be returned to Earth within hours or days, but that option won't be available to a Mars-bound crew. However, technologies enabling medical support in space are being developed. The May issue of *Focus* reported on a competition to design a 'tricorder', a tablet-sized device able to



Space explorers suffer different health problems to their Earth-bound friends

“An ISS astronaut could be returned to Earth within hours or days, but that option won't be available to a Mars-bound crew”

diagnose a range of conditions. Meanwhile, a lightweight MRI (magnetic resonance imaging) scanner is being developed for the ISS. As well as being able to detect problems such as incipient tumours, the scanners could be used to measure the astronauts' routine bone and muscle loss.

As for surgery, even if an experienced surgeon were available, the lack of gravity would complicate everything about a routine procedure. A Nebraska company called Virtual Incision is pioneering a miniature robot surgeon, which could be inserted inside the patient's body to perform quite complex surgery without the need for major incisions.

As a living environment, space has long-term health challenges. On the other hand, an old dream of space pioneers was that the cosmos may actually be good for you. In 1968, Arthur C Clarke outlined possible advantages of zero gravity for burns victims and patients undergoing post-operative therapy, and spoke of the wildly speculative possibility that life expectancy could be improved if gravity were removed. A retirement home in Earth's orbit? Sounds good to me. ■

STEPHEN BAXTER is a science fiction writer who has written over 40 books. His latest is *Ultima*, published by Orion

MATERIALS

Charging ahead with the future



WRITING COMPETITION

Winner in under-21 category: Emily Clements

SICK OF WAITING for your mobile phone to charge? A team of researchers from Stanford University think they've found a solution: they've created an aluminium-ion battery that can charge up your phone in just 60 seconds.

The team of researchers, led by chemistry professor Dr Hongjie Dai, has developed a battery that offers many significant advantages over the conventional lithium-ion batteries used in many gadgets and today's electric vehicles. Let's take a look at what makes the Stanford aluminium-ion battery such an important breakthrough.

The aluminium-ion battery is flexible. The Stanford team placed the aluminium anode and graphite cathode, along with an ionic liquid electrolyte, inside a polymer-coated pouch. The battery is supple, but it is also non-flammable – you can find evidence of the team drilling a hole through the pouch to demonstrate that it doesn't catch on fire. And even more impressive is that the power lingers for a few seconds after the hole is made. It's also relatively inexpensive and more environmentally friendly than typical AA and AAA batteries.

"Millions of consumers use 1.5-volt AA and AAA batteries. Our rechargeable aluminium battery generates about two volts of electricity. That's higher than anyone has achieved with aluminium," said Dai. "We accidentally discovered that a simple solution is to use graphite, which is basically carbon. In our study, we identified a few types of graphite material that give us very good performance," he added.

"The electrolyte is basically a salt that's liquid at room temperature, so it's very safe,"



Scientists at Stanford designed this flexible aluminium-ion battery

explained Stanford graduate student Ming Gong.

Though the battery only generates around two volts of electricity, which is around half that of a typical lithium-ion battery, the researchers are confident they can improve on this. "Improving the cathode material could eventually increase the voltage and energy density," said Dai.

So how are aluminium-ion batteries better than lithium-ion? Despite its overall advantages, lithium-ion has its drawbacks. It's delicate and needs a protection circuit to maintain safe operation, which limits the peak voltage of each cell during charge and prevents the cell voltage from dropping too low on discharge.

Lithium batteries, as well as standard alkaline ones, are toxic and must be disposed of with care. Billions of small lithium batteries power the assortment of gadgets that we

can't live without. Replacing them with aluminium batteries would eliminate the environmental risk.

Since the aluminium-ion battery weighs more than a lithium-ion one, and since at the moment it doesn't have enough power to keep a phone running, it's improbable for it to be in any device for the time being. Perhaps, in the near future, science will catch up with the idea.

Perhaps the aluminium-ion battery may be deployed on the electricity grid one day. It might be the perfect fit to provide balancing and reserve power to the electric grid, in essence buffering the ever-present gap between supply and demand. This application requires high-power batteries with the capability to charge and discharge many times without failing.

In 1859, the French physicist Gaston Planté invented the first

rechargeable battery. It was based on lead acid, a system that is still used today. The very first attempt to develop the Li-ion battery pack began in 1912 by an engineer named GN Lewis, but it wasn't until the 1970s that the first non-rechargeable lithium battery packs became commercially accessible.

In the past hundred years we have transformed everything. Technology is advancing faster than ever. In the last 50 years we have achieved things that many thought impossible just a couple of hundred years ago.

Everything has a battery these days – but today's battery is a toxic hazard. Maybe the aluminium-ion battery will be the eco-friendly, cheap to produce, high performance future of batteries.

EMILY CLEMENTS is 14 years old and is currently a student

Channa andrao



Leptobrachium bomp



Protobothrops himalayansus



Musa markkui



Elachura formosa

NATURE

Six-year survey discovers over 200 new species

A BLUE-EYED frog, a bejewelled snake and a walking fish are among the new species discovered in the Eastern Himalayas, an area that covers parts of northeast India, Bengal, Nepal, Bhutan and Tibet.

The findings come in a report published by the WWF following a six-year survey of the region's biodiversity. The species found include 133 plants, 39 invertebrates, 26 fish, 10 amphibians, one bird, one reptile

and one mammal. Among them were *Leptobrachium bomp*, a frog with strikingly blue eyes and black vertical pupils; *Channa andrao*, an air-breathing snakehead fish that can survive on land for up to four days and

can cover quarter of a mile by wriggling over wet ground; and *Protobothrops himalayansus*, a lance-headed pit viper that is so gem-like it could pass as a carefully crafted piece of jewellery.

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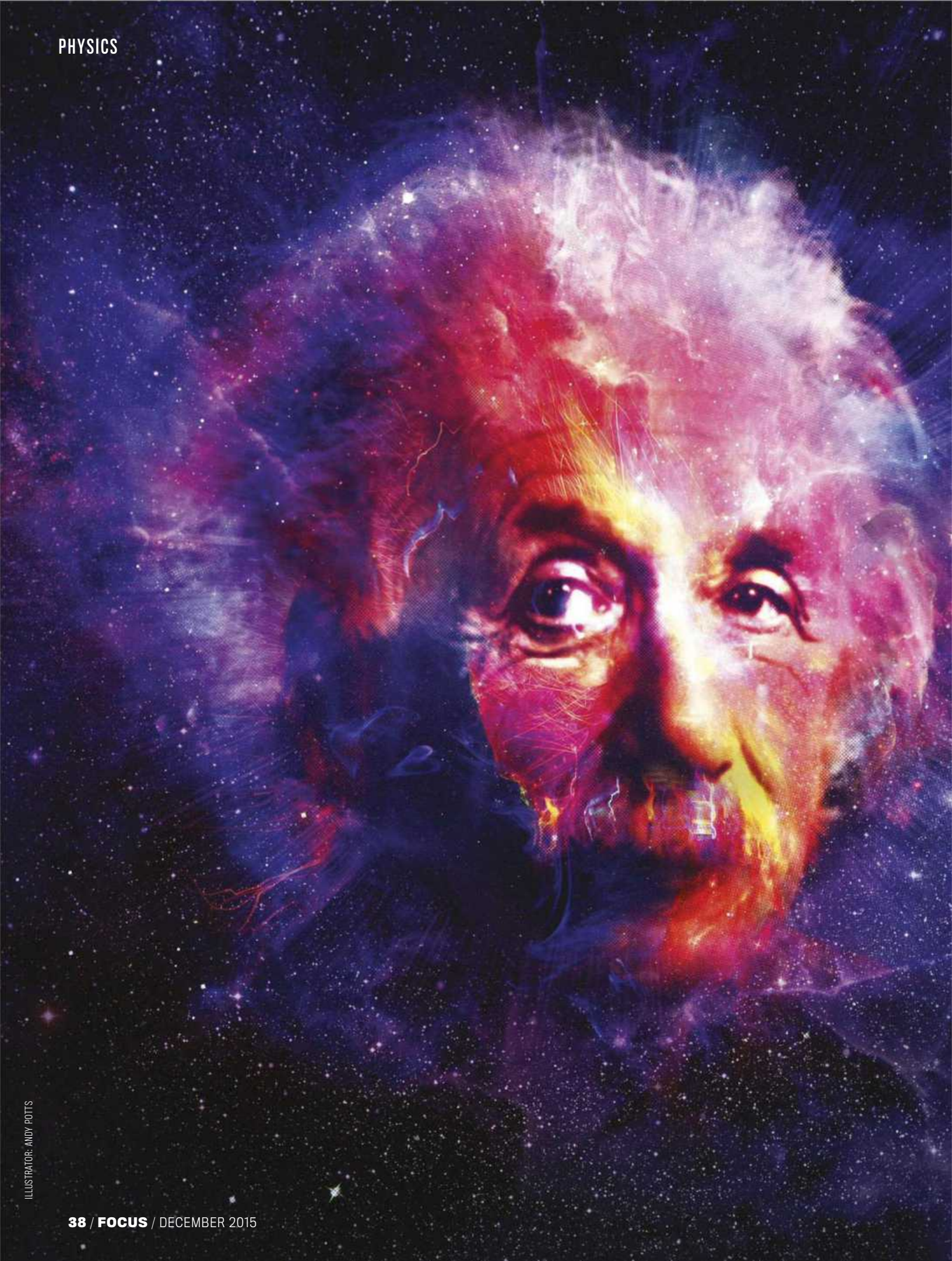


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RELATIVITY ON TRIAL

One hundred years ago, Albert Einstein wrote a groundbreaking theory that transformed physics forever. But are there any chinks in its armour?
Marcus Chown delves deeper



AT THE HEIGHT of WWI, in November 1915, German physicist Albert Einstein published a revolutionary theory of gravity. Not only did General Relativity show that Isaac Newton, arguably the greatest scientist to have ever lived, was wrong, it predicted black holes and that the Universe had been born in a Big Bang. It even showed, at least in principle, how to build a time machine.

The key thing Einstein recognised is that, in any small region of space, gravity and acceleration are the same thing. He came to this conclusion after considering Galileo's 17th-Century observation that all bodies, irrespective of their mass, fall at the same rate under gravity, hitting the ground at the same time if dropped from the same height. How could this be?

Einstein imagined a spacecraft far away from the Earth, which is accelerated at $1g$. If an astronaut inside lets go of a feather and hammer from an identical height, the floor accelerates up towards them at $1g$ and both objects hit the floor at the same time. If the windows are blacked out and the astronaut doesn't know they are in space, they might conclude they are experiencing gravity on Earth.

Einstein deduced that we feel gravity because we are accelerating. We do not realise it – and this is the incredible part – because matter warps the



WHAT IS GENERAL RELATIVITY?

The General Theory of Relativity describes how mass and energy cause the fabric of space-time to warp, giving rise to what we perceive as gravity. This theory built on Albert Einstein's earlier Special Theory of Relativity. Both theories are based on the idea that the laws of physics act in the same way everywhere and that the speed of light is constant. From this starting point, Einstein deduced that as everything is moving relative to everything else, different viewers see the same event differently. This is where the theory gets its name.

→ four-dimensional space-time it sits in. There is a valley we cannot see in the space-time around Earth. Our 'natural' motion is to take the shortest path, or the path of least resistance, through space-time – that is, to fall to the bottom of the valley. The Earth's surface obstructs us, pushing back. This is how we experience gravity.

In a nutshell, this is General Relativity. As theoretical physicist John Archibald Wheeler said: "Matter tells space how to curve. And curved space tells matter how to move." The theory has passed every test in the past century, predicting and explaining phenomena beyond the scope of Newton's theory. But it is known to break down in the 'singularity' at the heart of a black hole and in the Big Bang. So physicists are searching for a flaw that points the way to a deeper, more fundamental concept that will fill in the gaps of Einstein's theory. One key prediction that has yet to be confirmed is the existence of gravitational waves...

CATCHING WAVES

Gravitational waves are ripples in the fabric of space-time, which spread outwards from an accelerated mass like ripples on a pond. The problem is that space-time is about a billion billion billion times stiffer than steel. This means it takes a lot to vibrate it and create gravitational waves. Only the most violent astrophysical events such as the birth or merger of black holes or the collision of super-dense stars are capable of causing vibration.

On 27 November this year, the European Space Agency (ESA) will launch LISA Pathfinder, a mission to test the concept of a space-based gravitational wave detector. The idea of LISA,

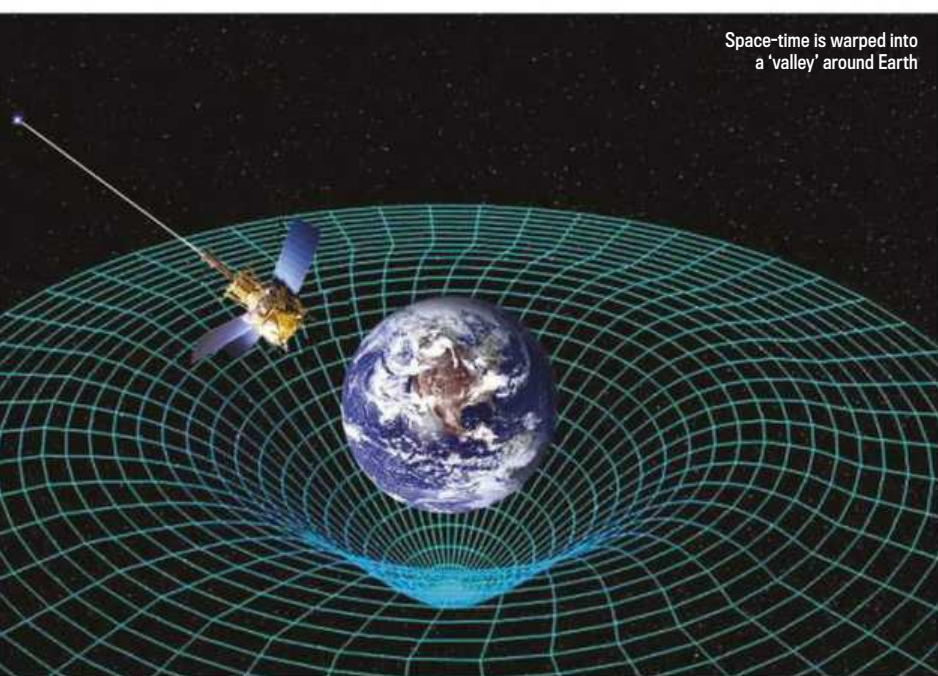
The LISA Pathfinder mission will test the concept of a space-based gravitational wave detector



Left: Albert Einstein published his General Theory of Relativity in 1915 – the same year this image was taken

which stands for Laser Interferometer Space Antenna, is to put a giant equilateral triangle in space, probably in 2034. The triangle will consist of three satellites, somewhere between one million and five million kilometres apart, bouncing laser light back and forth using mirrors. Think of the sides of the triangle as giant rulers. A passing gravitational wave is expected to alternately stretch space in one direction and squeeze it in a perpendicular direction, so the trick will be to look for subtle changes in the length of the rulers. "We expect to be able to detect change as small as the width of an atom over millions of kilometres," says LISA Pathfinder Project Scientist Paul McNamara.

Gravitational wave experiments have been built on Earth, but background vibrations of the ground mimic real sources, making them blind to the lowest frequency of gravitational waves. Such waves should be detectable by LISA. In addition, there should be a 'background' of tens of millions of events caused by white dwarf-white dwarf binaries in the Milky Way. 'Binaries' are systems consisting of two stars, orbiting a common centre of mass. "There is also a chance that a space-borne detector will be able to



Space-time is warped into a 'valley' around Earth

directly measure primordial gravitational waves produced in the first split-second of the Big Bang,” says McNamara.

“Electromagnetic waves allow us to ‘see’ the Universe, whereas gravitational waves will allow us to ‘hear’ it,” says McNamara. “Imagine going to an orchestra recital and only being able to watch the musicians without hearing any sound... now turn on the sound... this is what it will be like when we start to observe the Universe with gravitational waves.” Prepare yourself for the cosmic symphony.

GOING DEEPER

The fact that General Relativity breaks down in the ‘singularity’ of the Big Bang and a black hole, where the density of matter skyrockets to infinity, is not very helpful in trying to find a deeper,



The South Pole Telescope is part of a global array called the Event Horizon Telescope that aims to study the black hole at the Milky Way's centre



➔ more fundamental theory. The hope is that General Relativity might reveal a chink in its armour in less extreme circumstances. This is the idea behind an Earth-orbiting experiment called Satellite Test of the Equivalence Principle, or STEP, which is seeking NASA funding. "If it gets the go ahead, it could fly in six years," says Paul Worden, one of the originators of STEP in 1971.

The 'Equivalence Principle' is the fancy name for gravity being indistinguishable from acceleration so that all masses fall at the same rate. Since the principle is the foundation of General Relativity, it is a key place to look for an anomaly. Galileo is supposed to have dropped different masses from the Leaning Tower of Pisa, and Apollo 15's Commander David Scott repeated the experiment – with a hammer and a feather – on the Moon in 1971. STEP will suspend four pairs of 'test masses' made of at least three different materials, such as beryllium, niobium and platinum-iridium, and see whether they move relative to each other.

The masses will be inside a tank of liquid helium to insulate them from external temperature fluctuations and surrounded by a superconducting

"Electromagnetic waves allow us to 'see' the Universe, whereas gravitational waves will allow us to 'hear' it"

shell to shield them from electromagnetic interference. Microthrusters will counteract the atmospheric drag on the satellite, so the freefall of the test masses will be nearly perfect.

The key to the experiment is that a satellite in Earth orbit is always falling away from its desired straight-line path but never gets any closer to the Earth because the Earth's surface perpetually curves away from it. In other words, it is falling forever. This will enable small differences in the rate at which different masses fall to be magnified.

The Equivalence Principle is known to hold to one part in a trillion, but STEP will better that by another factor of a million. All attempts to unify General Relativity with quantum theory involve new forces, which may affect different materials in different ways. "A violation is basically the discovery of a new force of nature, or something really weird," says Worden. "If there's no violation, at least to experimental accuracy, we can rule out a lot of theories of gravity but not Einstein's."

THE 'HOLE' STORY

But General Relativity might be put to its toughest test within only a year or two. So far,



5 WAYS

YOU CAN SEE EINSTEIN'S THEORY IN REAL LIFE

MASS

The 'Higgs field' accounts for only about 1 per cent of your mass. 99 per cent is due to a relativistic effect. Specifically, the quarks that compose you are moving so fast they gain mass. Without Einstein, you would weigh only about 1kg!



SUNLIGHT

According to Einstein, mass is a form of energy and so can be converted into other forms of energy. This is what is happening in the Sun's core, where nuclear reactions convert about 0.7 per cent of the mass of hydrogen nuclei into heat and, ultimately, sunlight.

GOLD

An atom absorbs and re-emits light when an electron moves between orbits. The light's energy (colour) depends on the energy difference between the orbits. Gold ought to appear silver, but its innermost electrons move so fast that they gain mass. This changes the light its atoms reflect, making it appear gold.



THE UNIVERSE

The distant Universe seen through telescopes is not actually there: it's an illusion. The reason is that matter creates valleys in space-time which light from distant objects must negotiate on its way to Earth. The Universe is therefore distorted as if seen through frosted glass.

SLUGGISH SATELLITES

If you have a smartphone or a sat-nav, it calculates your location relative to a constellation of Global Positioning satellites. When these swing in close to Earth, they experience stronger gravity and their on-board clocks slow. This effect must be compensated for to calculate your location.



GENERAL RELATIVITY'S SUCCESSES

THIS ISN'T THE FIRST TIME EINSTEIN'S FAMOUS THEORY HAS BEEN PUT TO THE TEST



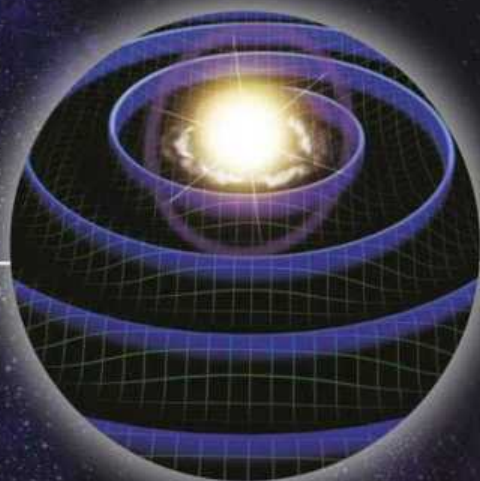
MERCURY MYSTERY

According to Einstein, the gravity near the Sun is stronger than Newton would have predicted. This causes the elliptical orbit of Mercury to gradually change its orientation. It 'precesses', which means the planet traces out a rosette-like pattern around the Sun. Before Einstein, this was such a puzzle that it led to the suggestion of a planet - Vulcan - tugging on Mercury.



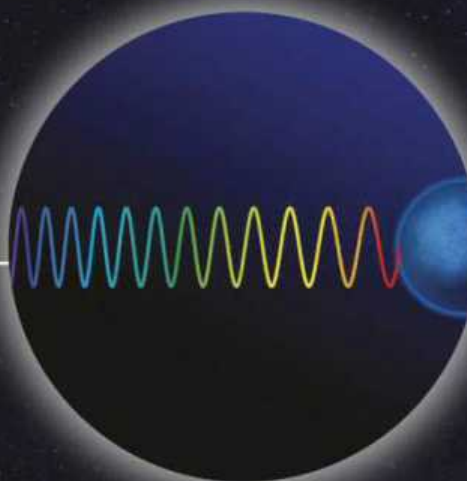
TIRED LIGHT

As light climbs out of the valley in space-time around a massive object like a star, it loses energy. This is equivalent to a reduction in its frequency and is known as a gravitational red shift. It has been observed in the light of dense, white dwarf stars. In 1959, it was even observed in light climbing up a 22.6m tower on Earth by physicists Robert Pound and Glen Rebka at Harvard University.



RIPPLING GRAVITY

Although gravitational waves have yet to be detected directly, they have been detected indirectly. In 1974, Russell Hulse and Joseph Taylor discovered two super-dense neutron stars orbiting each other. By observing the 'binary pulsar', or PSR B1913+16, they determined that the stars are spiralling together and losing orbital energy. This lost energy is exactly the amount Einstein's theory predicts they should be radiating into space as gravitational waves.



BENT LIGHT

Einstein calculated that the gravity of the Sun would bend the trajectory of light from distant stars by twice the amount Newton would have predicted. The only way to observe stars close to the Sun is during a total eclipse when the bright solar disc is blotted out by the Moon. During the total eclipse of 29 May 1919, the English astronomer Arthur Eddington confirmed that the positions of stars were shifted, exactly as Einstein had predicted.



“An image would be a turning point in our understanding of black holes and gravity”

Doeleman of the Massachusetts Institute of Technology and leader of the EHT team.

The key thing is to observe the black hole’s event horizon – the point of no-return for in-falling matter and light – and see whether it behaves as predicted by Einstein or even whether it exists. Stephen Hawking suggested it might not. This will test Einstein’s theory in the realm of strong gravity, where it has never been tested before. “An image would allow us to test General Relativity at the black hole boundary but, just as importantly, it would make the case for the existence of black holes as solid as it is ever likely to be,” says Doeleman. “An image would symbolise a turning point in our understanding of black holes and gravity.”

Doeleman is being modest. It is possible that the first image of a black hole event horizon will be an iconic image to rival the Apollo 8 image of the Earth rising above the Moon.

In the world of science, 100 years is an awfully long time. Countless theories have been proposed since Einstein published his famous paper, with many of them turning out to be nonstarters or dead ends. After a century of extraordinary success, it still remains to be seen how far the General Theory of Relativity can be stretched before reaching its breaking point. Could its time be finally up? After all, even Einstein viewed the theory as being incomplete. If STEP, LISA or the EHT are able to find even the tiniest hole in its venerable armour, scientists could be on the brink of formulating a new theory of gravity, or maybe even making the first tentative steps towards the elusive ‘theory of everything’. ■

MARCUS CHOWN is a science writer and author of *What A Wonderful World: Life, The Universe And Everything In A Nutshell*

→ the theory has been checked only in situations where gravity is relatively weak. Nobody has tested it where gravity is strong – close to a black hole. That could all change when the Event Horizon Telescope (EHT) images the black hole at the centre of our Milky Way, probably in 2017.

The EHT is an array of cooperating radio telescopes scattered around the globe. The radio signals recorded at each site are flown together and combined on a computer at Haystack, Massachusetts to simulate a giant dish the size of the Earth. The bigger the dish and the shorter the observing wavelength – EHT is using 1.3mm – the more it can zoom in on details in the sky.

The trouble with black holes is they are very difficult to see. Stellar-mass ones are too small and the supermassive black holes in the cores of other galaxies, with up to 30 billion times the mass of the Sun, are too far away. Only one black hole is within reach – the one 26,000 light-years away at the centre of the Milky Way. Sagittarius A*, as it is called, will be magnified in size by its own intense gravity. “It will appear as big as a grapefruit on the Moon viewed from Earth,” says EHT scientist Shep

Above: The Apollo 8 image of Earth taken from the Moon is pretty iconic – but a photo of a black hole event horizon could be even more impressive

DISCOVER MORE!



The Infinite Monkey Cage will be featuring a guide to General Relativity – check *Radio Times* for details

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INVASION OF THE LIONFISH

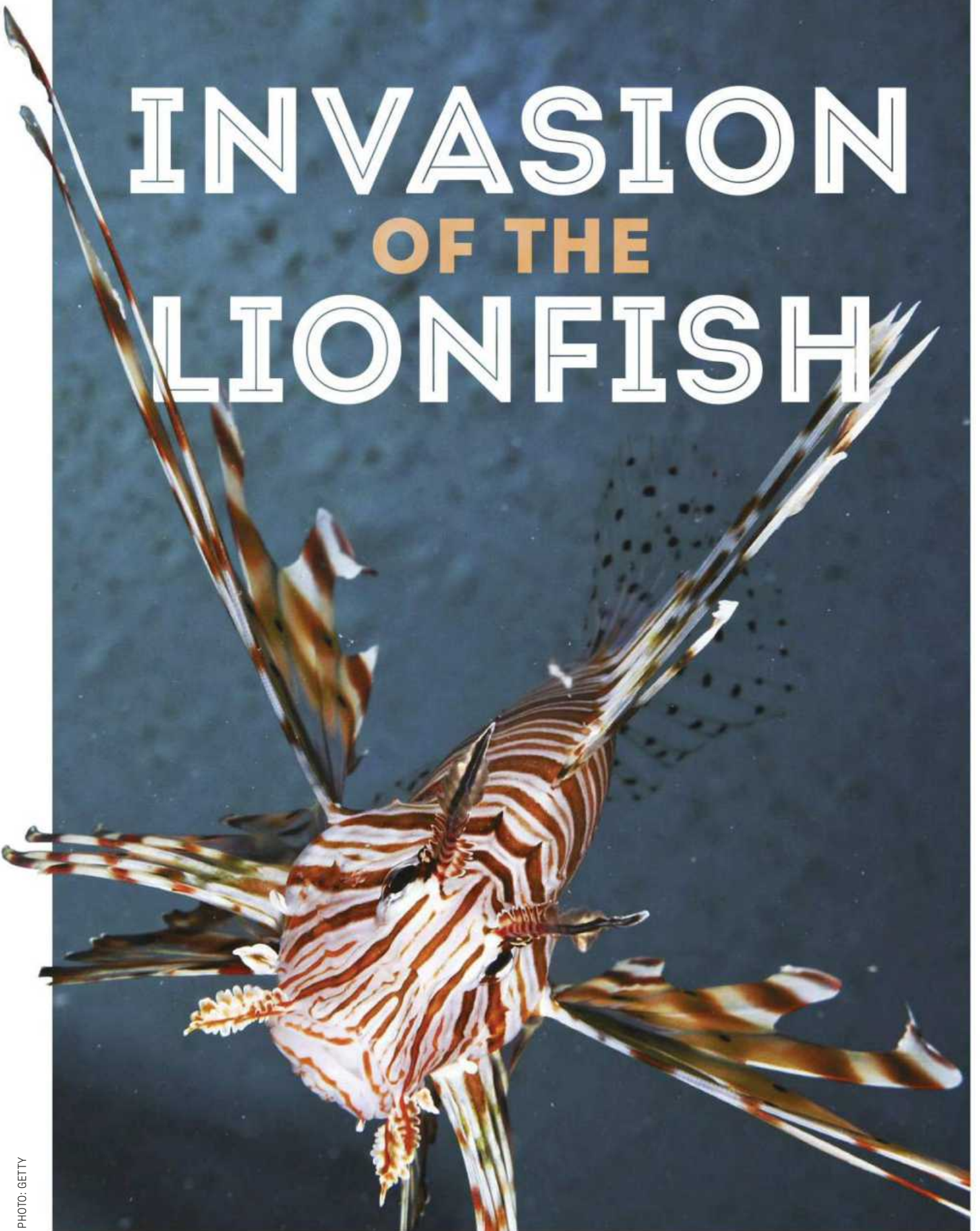


PHOTO: GETTY

Invasive lionfish are wreaking havoc on the reefs of the western Atlantic and the Caribbean. So what can we do? Well, we could eat them, says **Helen Scales**

WHILE SCUBA DIVING on the coral reefs surrounding Abaco Island in the Bahamas, I spy a lionfish fluttering in the distance. These graceful animals, with their shroud of venomous spines, normally live on the other side of the world. But here they're considered to be menacing pests. I watch the creature hovering in front of me and feel strangely conflicted – it is beautiful, but it has to go. It doesn't flinch as my dive buddy skewers it with a long metal spear. This lionfish will be cooked and eaten, and conservationists are encouraging other people to tuck in to the tasty fish in an attempt to control the spread. But some are also trying to persuade other fish-eaters to get in on the act, including those most toothsome predators: sharks.

INVASION OF THE SEAS

Experts blame the lionfish problem on the pet trade. It most likely began when captive fish – perhaps as few as 12 individuals – were released from aquariums in Florida. When those founding fish began to proliferate, people got worried. Lionfish are skilful hunters with enormous appetites. In their new territories they started to gorge themselves on numerous species of smaller fishes and invertebrates, some of which were already threatened before the arrival of the invaders. The concern was that the lionfish could strip coral reefs bare, devastate local ecosystems, damage tourism and impact local fisheries in one fell swoop. There was little time to investigate the matter before lionfish scattered far and wide.

In 2007, a single lionfish showed up in a group of remote Cuban islands called the Gardens of the Queen. Divers flocked to photograph the fish, but it wasn't alone for long. "Within a matter of weeks we had 10 places where we could see lionfish," says Cuban marine biologist and diver Andrés Jiménez Castillo. "Now they are everywhere."

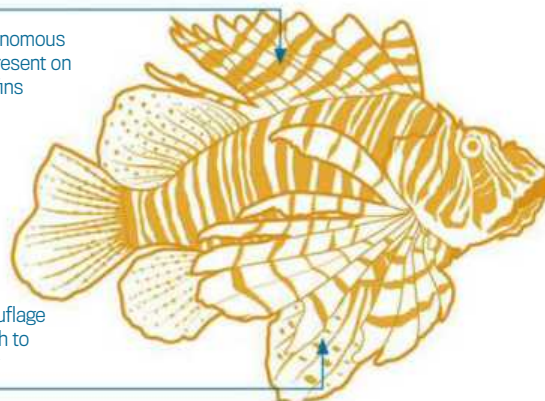
Lionfish are formidable invaders. They can spawn throughout the year and just one female can release up to 30,000 eggs every four days. These floating clumps of eggs ride ocean currents for up to a month, drifting hundreds or even thousands of miles before they hatch and form a whole new generation of lionfish. ➔

KNOW YOUR ENEMY

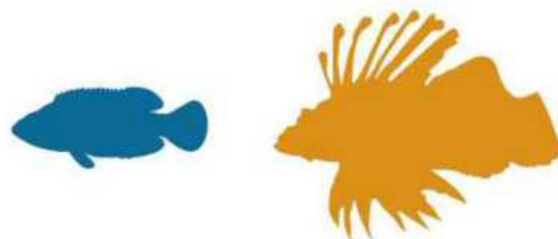
Around 18 venomous spines are present on the animal's fins

Clever camouflage allows lionfish to ambush prey

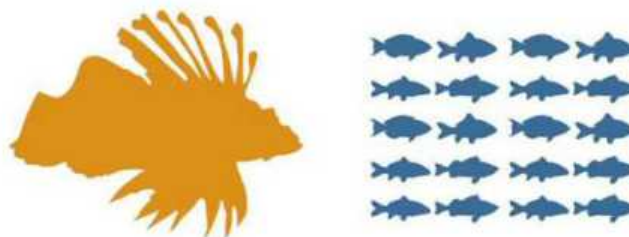
Lionfish eat as many as 70 different species



ONE FEMALE CAN RELEASE UP TO
30,000 EGGS
EVERY 4 DAYS



A lionfish can eat prey measuring two-thirds of its body length



One lionfish can consume 20 fish in half an hour

LIONFISH SPREAD



1993



2005



2010



Lionfish measure up to 48cm in length and occur at much higher densities in their invasive range than their native habitat

As the lionfish swept through Cuban reefs, Castillo and his colleagues began to notice that fewer were spotted at dive sites where there were lots of sharks. They wondered if perhaps the sharks were eating lionfish and landed on the idea of giving them a helping hand.

A SEARCH FOR SOLUTIONS

The native range of the lionfish stretches throughout the Indian and Pacific Oceans. Here, they are hunted by groupers and sharks. In the Caribbean, however, predators aren't used to seeing the spiny fish and don't seem to hunt them. Nevertheless, when they were offered a lionfish on the end of a diver's spear, the Cuban predators soon caught on.

Castillo saw that groupers, especially the metre-long Nassau groupers, quickly learned to grab lionfish from his spear and swallowed them whole, spines and all. They even started following divers around and hovering expectantly next to lionfish, apparently waiting to be fed. In contrast, the sharks have been more reluctant. "You can see they don't like it," says Castillo. Sharks tend to pick at a dead lionfish, spitting it out repeatedly and turning it around in their mouths before trying to swallow it.

"There is evidence to suggest that another predator is effective in reducing lionfish numbers: humans"

So will sharks help to control numbers of the invasive lionfish? It's debatable whether they will get a taste for this exotic prey and start hunting lionfish of their own accord.

It could be too late for sharks to leave their mark on the lionfish invasion. Some scientists think that if Caribbean reefs hadn't been heavily overfished by the time lionfish came along, the invasion might not have been so bad. Perhaps healthier populations of predatory fish could have helped stop lionfish in their tracks. One study conducted in the Bahamas supports the theory that reefs with higher densities of predators had fewer lionfish, as Castillo saw in Cuba. But not everyone agrees.

"A lot of people think predators are the solution," says John Bruno, a marine biologist from the University of North Carolina and co-author of a



Attempts to encourage sharks to eat the lionfish have been unsuccessful



A three-pronged spear prevents the lionfish sliding down the pole and injuring the diver



Lionfish University photographed this grouper eating an invasive lionfish



Sharks don't seem to recognise the lionfish as prey

region-wide lionfish study. His team's research paints a different picture. On 71 reefs, from the Bahamas to Belize, they found no relationship between the density of lionfish and native predators. What they did find was evidence to suggest that another predator is effective in reducing lionfish numbers: humans. Bruno and colleagues consistently saw lionfish in lower densities inside marine protected areas – not because of abundant sharks, but most likely because reserve managers organise regular culls.

Lionfish derbies have become popular across Florida and the Caribbean where divers compete to catch as many lionfish as possible on a single day, from dawn until dusk. Cash prizes are up for grabs for catching the smallest and largest lionfish. The numbers caught can be staggering. During the 2013 derby on Green Turtle Cay in the Bahamas, 62 divers brought back 1,204 lionfish. Lionfish have venomous spines that can cause extreme pain, nausea and breathing difficulties in humans. Once these spines have been removed, however, the fish can be filleted just like any other fish. In Cuba, though, eating lionfish is something Castillo no longer gets to do.

"It's very hard for us to catch them for food," he explains. "The sharks don't allow us to leave the



Lionfish can be safely cooked and eaten, once the venomous spines have been removed

water without giving them the lionfish we've caught." With the situation getting potentially dangerous, Castillo has stopped hunting lionfish to feed to local sharks. Other conservation groups, such as Florida-based Team Frapper, are trying another tactic and are attempting to design lionfish-specific traps to capture the invaders.

WHAT NEXT?

Plenty of unknowns remain in the unfolding story of the lionfish invasion. Their appetite for native fish is proven, but the effect this has is contentious. One study in the Bahamas showed that from 2008 to 2010, local fish populations crashed by 65 per cent as lionfish increased. Elsewhere, effects have been harder to find. One thing most experts agree on is that lionfish are in the western Atlantic for good. As other invasive species have shown, there's little chance of eradication. We may just have to wait and see the long-term effects of the invasion. But until then, if you see lionfish on the menu in the Caribbean, why not give it a try? ■

HELEN SCALES is a marine biologist, author and broadcaster whose latest book is *Spirals In Time*



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THE END OF WORK?

According to a new report, advances in artificial intelligence and robotics mean that soon, most of the jobs we do today will be automated. Will that leave us jobless, or will it free us from the 9 to 5?

Russell Deeks finds out





KEVIN SURACE

CEO, APPVANCE

THERE IS NO doubt in my mind that in the next 10, 20, 50 years, most of the jobs that we know today are going to disappear, because it will be cheaper, quicker and far more efficient to have those tasks carried out by robots and artificial intelligence. But as I see it, the huge wave of disruption that's coming presents humanity with a great opportunity.

The kinds of disruption I'm talking about are already happening – in many cases, without people even realising it. Take driverless cars: to most people they still seem futuristic, but they'll be on the road in most parts of the world by 2020, and by 2030 human-based cars will be outlawed in many cities, no question. The Bay Area in San Francisco already has driverless buses on certain routes. So people need to wake up and start thinking about how many millions of people around the world are employed in driving things – because that's all gone in 10 years' time.

You can also look at the catering industry, where many restaurants are using digital ordering via an iPad rather than a human waiter, and the hotel industry, where the Savioke robot butler brings towels to your room. Robots

Google has put its self-driving equipment into a number of different car brands



T

HERE'S BEEN MUCH talk lately of an 'existential threat' from artificial intelligence systems, particularly those embedded within robots. Make machines smart enough, goes the theory, and they'll soon realise that they could run Planet Earth a lot more efficiently without those pesky, meddling humans.

But while such a future 'singularity' may be a terrifying prospect, it's also not likely (most experts agree) to happen any time soon. Meanwhile, there's another, slightly more prosaic question that's often overlooked: never mind robots destroying our species, what exactly are we going to do when they've taken all our jobs?

That's the question we've invited a group of AI and business experts to discuss. We were struck by Appvance CEO Kevin Surace's recent TED talk, in which he paints a compelling picture of a future in which none of us have to work and we're all free to dedicate our lives to art and education. Over these pages, Kevin expands upon his ideas, while AI experts Mateja Jamnik from the University of Cambridge and Andrew Lea of the British Computer Society discuss whether the current state-of-play in AI research matches up with Kevin's vision, and Jon Andrews of management consultants Price Waterhouse Coopers (PwC) offers a view from the business world.

As you'll discover, there's no broad consensus on how new technologies will impact upon our working lives. But all our experts agree on one thing: the times, they are definitely a-changin'...

PHOTO: GETTY X2, PRESS ASSOCIATION

like Savioke will soon be able to deliver your food, too, while kitchen processes are becoming so automated that in the next five years you'll see burger outlets actively touting the fact that no human has touched your food. And it can be custom-made for you, at a quarter the price of the hamburger joint across the street... that will take off, no question.

Those are the easy examples we can point to right now. Doctors are the ones people laugh at, but there are already robots run by doctors today; you could take the same robot, run it by a computer and it would do a better job. You can program the computer for every possible situation that could occur in the human body, and it will make all the trade-offs in 10 milliseconds that a doctor would take a minute to make. You're already dead by then! It's only really the FDA that's stopping us from doing computerised surgery already – it's not a technology problem any more, it's a regulatory problem and a psychological one.

So all these things are happening already, and our world is going to change drastically.

CHANGE IS A-COMING

We've seen this situation before, of course. In the agricultural age, over 90 per cent of the population worked in farming. They couldn't imagine what would happen if most of their jobs were taken over by machines. Today, just 1.5 per cent of people in the US work in agriculture, and the rest found jobs elsewhere – making the machines and doing other things. So we were able to reinvent jobs in the past, including when manual labour was taken away. We did manage to break through those walls, but from one side of the wall no-one could ever see what lay on the other side.

The difference, though, is that now we've got machines that can take over virtually every manual task, and they're beginning to take over many mental tasks, too – all at higher quality and lower cost. So that does make us ponder what seven billion people on Earth will do with themselves. It could be that learning becomes more valued, and that's how you earn a living... or it could be that the concept of 'earning a living' itself is in fact outmoded, that there's a different kind of utopia. In my TED talk I suggested that we could enter a new Renaissance, where work in the traditional sense is not what's valued any more, but there's great value in art.

Some people have said that's a ridiculous dream, or that the only people who'll have jobs will be the robot overlords. I prefer to think that, as humanity moves forward, there'll come a time where humanity learns to take care of itself in a new way. But everybody needs to wake up to the fact that this is coming. Little by little, jobs will be taken from people, and we need to start thinking about what those people are going to do. There's about



Above: In Canada, some restaurants allow guests to place their food orders digitally – could this be the end of waiting staff?

20 per cent of people in any society that can only really do manual labour, and we probably can't teach them to program computers. So what will these people do? What can we all do so that we're contributing in a new way, and what will those contributions be?

There are still certain barriers to all this, of course.

One barrier that's been overcome already is cost: it's now cheaper to manufacture goods using robots than with Chinese labour, which is among the cheapest in the world. But there are still big steps forward needed in the field of AI, and there have to be breakthroughs in societal norms, too. In fact, the latter could be the biggest hurdle. But these changes are definitely coming: not next year, but not in 100 years, either. We're looking at 10 or 20 years down the line... 50 at the most.

What's just over the horizon isn't necessarily a techno utopia – it could turn out to be a techno nightmare. But it is the techno future, and we need to be having these conversations now.

Right: The Savioke robot distributes towels in hotels and can even navigate between floors



Delivery drones
wouldn't mind working
the weekends...



MATEJA JAMNIK

SENIOR LECTURER, UNIVERSITY OF CAMBRIDGE COMPUTER LABORATORY

HAVING GONE THROUGH a 40-year 'AI winter' after too many inflated promises were made in the 1970s, artificial intelligence is getting academics and industrialists excited once more. Google, for instance, recently purchased the AI company Deep Mind for a reported \$400m, and is also developing a driverless car, while Amazon is investing heavily in the drone delivery system.

With news stories about drones carrying our parcels, and humanless factories in China, it's not surprising that many people are concerned about what is going to happen to their job. The most pessimistic studies predict that as many as 47 per cent of jobs will disappear in the next 20 years. So, will robots replace us and take all our jobs, doing them better, faster and cheaper to boot?

I don't think they will – but they will change the way we work. The artificial intelligence systems of the future will have a profound effect on what we do and how we do it, much as the Industrial Revolution affected manual jobs of the 19th Century, and the digital revolution transformed communication in the 20th Century.

A lot of repetitive, menial work will disappear and be replaced by automated robots. But this is no bad thing: many of those jobs are soul-destroying and often injurious to health, and there's a shortage of people who want to do them. Potentially threatened

jobs might include factory workers, accountants, postal workers and human translators, to name a few.

But the main drive in artificial intelligence is to develop smart systems that will work *with* people. Big data, machine learning and super-computing power enable systems to find patterns far quicker than humans can. At the same time, we are developing systems that are getting better at cognitive tasks. In my own work, I'm modelling human intuitive reasoning, in particular with visual information, to enable machines to discover and learn new knowledge. I'm essentially humanising computer thinking.

I see the future in the hands of human experts, but heavily supported and helped by intelligent systems that are becoming more accurate all the time. Machines will assist and collaborate with humans to enable them to work more effectively as well as do things that are beyond human capability alone. In biomedicine, for example, intelligent systems can exploit multi-source big data to build models of complex patient cases with lots of co-occurring medical conditions.

However, as intelligent systems become ubiquitous, many ethical and safety issues arise. For example, who takes responsibility for a wrong or harmful decision by a computer program? While we have significant evidence that software can sometimes be more reliable than humans in making crucial decisions, I think that for the foreseeable future these systems will mostly be designed to collaborate with human experts, not replace them.

AUTOMATION THROUGH THE AGES



The spinning jenny was invented in 1765 and was still in use in the 20th Century

INDUSTRIALISATION

The first electronic computing machines emerged in the 1940s, with the programmable, all-digital Colossus machine at Bletchley Park arguably the first modern computer. By the early 1950s they were finding their way into offices, and as computing technology has continued to evolve over the years, they've taken on more and more previously 'human' tasks. While this has led to mass redundancies at times, the birth of computing has also created entire new industries.

COMPUTERS

Until the mid-18th Century, goods were manufactured by hand in small workshops, often in people's homes. The invention of the steam engine, the spinning jenny and machine tools changed all that, leading to the large-scale mills and factories we're used to today. But the new technologies weren't popular with everyone, and in the early 19th Century the Luddites in northern England took to sabotaging the machines that were taking away their jobs.



Operating a mainframe computer in the 1960s

FACTORY ROBOTS

In 1961, a programmable robot arm designed by George Devol and Joseph Engelberger was given the job of welding diecast parts onto automobile bodies on a General Motors assembly line in New Jersey. 'Unimate', as it was called, was the first production-line robot and paved the way for the widespread automation of manufacturing processes that took place in the 1970s and 80s and continues to this day.



Robotic welding at GM Motors in the 1970s

1ST CENTURY AD

Heron of Alexandria builds human-shaped automata

1941

Isaac Asimov's short story *Liar!* introduces his Three Laws of Robotics

1951

Chess and draughts programs run on the Ferranti Mark 1 computer at Manchester University

1959

MIT founds its AI Lab

1979

Backgammon-playing program BKG defeats the world champion

1997

Deep Blue supercomputer defeats chess champion Garry Kasparov

1999

Sony starts selling the AIBO 'robot dog'

2005

Ray Kurzweil predicts machines will be smarter than humans by 2045

2011

Siri, Google Now and Cortana launch

1941

Konrad Zuse builds the first programmable computer, the Z3

1950

Alan Turing proposes 'the Turing test' to measure computer 'intelligence'

1956

The term 'artificial intelligence' is used for the first time, at a conference at Dartmouth College in New Hampshire

1961

Unimation Unimate robot starts work at a General Motors factory

1986

First robot cars produced at the University of Munich

1997

The first RoboCup – a football tournament for robots – is staged in Nagoya, Japan

2002

The iRobot Roomba vacuum cleaner goes on sale

2009

Google builds its first self-driving car

2015

First robot-staffed hotel opens in Japan



ANDREW LEA

FELLOW, BRITISH COMPUTER SOCIETY

IF YOU WANT to discuss the impact of artificial intelligence on the world of work, you first need to look at what the phrase actually means. Artificial intelligence today consists of several discrete disciplines, resting on independent theories. A few current uses include: image recognition and neural nets for self-driving cars, optimised search algorithms, playing chess or planning routes, and recommendation engines in personal assistants. And there are many more.

Just as particle physics is searching for a 'theory of everything', so AI lacks (but is generally not searching for) a 'universal theory of thinking'. Having emerged from several decades in which AI was poorly regarded – partly due to failing to deliver on early over-expectations – AI is now finding practical applications. Insights emerging from such applied AI may eventually give rise to that theory of thinking.

Today, special purpose machines can displace people from specific manual tasks (digging tunnels with shovels, or walking from here to there) but the tools (the diggers or cars) are still controlled by people. So it is with computers: they've displaced us from specific tasks (adding numbers), but still need people to drive the spreadsheet. Machines and computers need people to decide to do anything: that is, to supply the initiative. Perhaps a general purpose machine, able to displace us from our work, requires general purpose AI.



Unexpected item in the bagging area! We're all familiar with the cry of these robots...



The da Vinci surgical robot can carry out minimally invasive operations

This self-service McDonald's machine in Manchester, UK, allows diners to order food



If so, what capabilities would that AI need? It would need a flexible, temporally aware reasoning system, able to call upon the special purpose sub-systems above. It would learn through training (supervised learning) and experience (unsupervised learning). It would need first class language understanding, able to cope with humour, sarcasm and contradictions. Initiative and self-motivation may require an awareness of self, possibly giving rise to emotions and even ethics. Finally, it may be able to program itself.

There are two possible routes to this kind of AI. Firstly, developing a theory of thinking and then engineering it. Secondly, setting up environments in which AI evolves through natural selection, without us understanding how it works – just as we don't understand how we ourselves think. It might sound far-fetched but this discipline, genetic programming, already exists.

An AI capable of these feats could pass a strong version of the Turing test: it could be given the rules of a new game in spoken English, and play it. It could decide to read this article, disagree with it, become bored and stop. But AI of that level – the kind of AI that might put us *all* out of work – is still some way down the line.



Surgeons in China control a da Vinci robot during an operation



JON ANDREWS

GLOBAL PEOPLE AND ORGANISATION LEAD, PWC

LAST YEAR, PWC produced a report entitled *The Future Of Work: A Journey To 2022*. It draws on five years of research and points to three potential future trends: a 'blue world' of huge corporations built on an employee base that works for them their whole career; an 'orange world' where most employment is on a freelance or short-term contract basis; and a 'green world' where a company is defined more by its corporate and social responsibility. All these scenarios are impacted by the digital revolution, and the pace of change is creating an unpredictable environment for employers and employees.

With advances in robotics and AI, we will definitely see more automation – including automation of things that people wouldn't dream of being automated today. But I don't believe that work itself is suddenly going to disappear – we've been promised 'the leisure society' several times before and we're still waiting for our *Jetsons*-style flying cars! History teaches us that when machines take away the need for manual labour, other jobs spring up to fill the vacuum. For instance, maybe drones can fight wars for us now but you still need human beings to build and service them, as well as IT security experts to keep them safe from hackers. As old jobs start to vanish, new jobs emerge that we hadn't previously imagined.

Technology advances will also change how and where people work. I believe that technology will empower the rise of the portfolio career – people will have their

own brands and sell their skills to those who need them, where they need them. And much of this work will take place virtually.

That points to another change that's coming: if we're all going to live longer, then we'll have to work longer, too. If somebody born in 2012 is going to live until they're 105, then they'll probably have to work until they're 85. It'll be a different sort of career: people might retire in the middle of it, they might have more flexible working and so on. We could see the rise of the part-time pensioner.

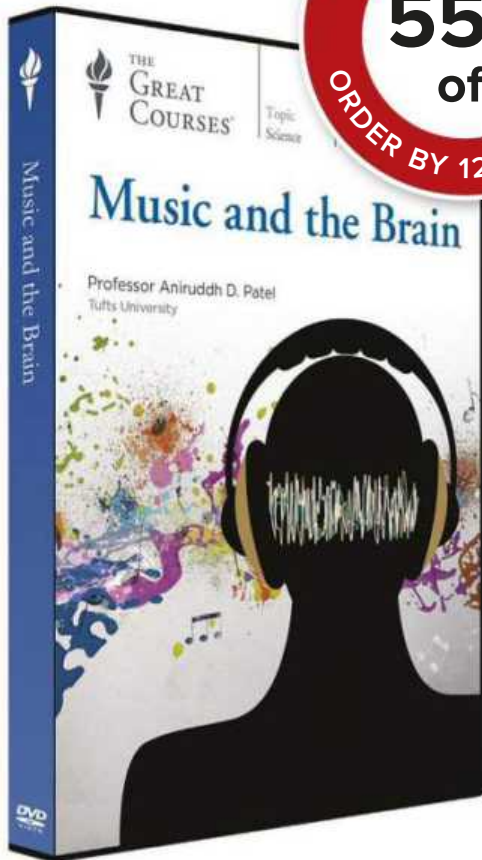
One thing is certain in this dramatically shifting world of work – change *is* coming, and there are lots of questions that both employers and employees need to start asking themselves as we prepare for world in which machines, artificial intelligence and human beings work side by side. ■

RUSSELL DEEKS is a freelance science and technology journalist, and Contributing Editor at *BBC Focus*

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WELCOME TO *THE WIRED, WIRED WEST*

Bristol will soon be home to one of the most advanced 'smart city' networks in the world. **Russell Deeks** investigates



THE CITY OF Bristol is changing. Even as you read this, finishing touches are being put to a network called Bristol is Open that will put one of the UK's largest cities – which also happens to be home to *Focus* magazine – among the most advanced ‘smart cities’ in the world. And it’s all happening because cable TV never really caught on in Britain.

A decade ago, cable company Rediffusion invested heavily in building a system of ducts below the city streets, to house the cabling for its TV network. When that company folded, some bright spark at the city council – whose exact identity seems lost in the mists of time – realised that might be a useful thing to own, and purchased the ducting for the city. In the intervening years, it’s been used to connect up council offices across the city, and to enable the B-Open data sharing network that’s used for, among other things, providing Wi-Fi hotspots and enabling interactive public art installations. But now the whole system has been kitted out with superfast 144-core fibre optic cabling, and linked up to the BlueCrystal supercomputer at the University of Bristol’s Advanced Computing Research Centre.

Paul Wilson, MD of the Bristol is Open project, takes up the story. “About five years ago, the Department for Media, Culture and Sport (DMCS) launched a funding initiative called Connected Cities. It was an ambitious project, but most of it just turned into the UK

At-Bristol science museum is taking on a role as a data visualisation facility

“Our network doesn’t connect to the internet... it’s a playground where people can start building the next internet”

broadband roll-out. Bristol, though, maintained its desire to something more innovative, and build a software-defined network. Because the city owned the ducting, we could do something other cities wouldn’t be able to.”

HOW IT WORKS

Bristol is Open will consist of a number of elements, all interlinked and working together. Firstly, there’s the fibre optic network detailed above. There’s also a wireless network running along the ‘Brunel Mile’, a pedestrian route linking the city’s Temple Meads railway station and harbourside areas, which is now kitted out with, in Wilson’s words, “All sorts of wireless connectivity comprising 3G, 4G, LTE... and 5G, which really just means ‘new stuff’, experiments. We’re even trialling Li-Fi, wireless connectivity using light instead of radio waves.”

And then there’s the ‘mesh’ network, which sees 1,500 lamp posts across the city equipped with various sensors and connected via an RF4 radio frequency network. All three networks – cable, wireless and mesh – are in turn linked both to the BlueCrystal supercomputer, and to the planetarium at the At-Bristol

science museum, which is taking on a new role as a data visualisation facility. It’s been upgraded with a dual-source 4K 3D projection system that beams 1.6 billion pixels per second onto its curved ceiling, and 7.1-channel surround sound – making it arguably the most advanced such facility in the world.

As At-Bristol’s CEO Phil Winfield explains: “It’s the only stereoscopic, active 3D planetarium in the UK. To the best of my knowledge, it’s also the only 4K-resolution planetarium in the UK – there are a few in Europe, but I believe we’re the only one in Britain. And it’s the only one in the world that’s linked into a supercomputer for data visualisation.”

Which is all very impressive, from a technical point of view. But what’s it all for?

WHAT IT CAN DO

It’s perhaps easier, first of all, to list some of the things Bristol is Open *won’t* do. It won’t bring superfast internet to every home in the city, for instance. It won’t make Bristolians’ smartphones work better. And in case you were worrying, it won’t give local authorities access to unprecedented amounts of information about local citizens (see the adjacent box

PHOTO: @T BRISTOL CATAPULT, BRISTOL IS OPEN

Bristol is Open MD Paul Wilson



‘Is Big Brother watching?’ for more on privacy concerns).

“If you look at Bristol is Open from a consumer angle, you could say ‘What’s the point?’,” admits Paul Wilson. “Because our network doesn’t connect to the internet, for example. It’s not about that – it’s a playground where people can start building the next version of the internet.”

Bristol is Open is, indeed, best viewed as a kind of technological sandbox, a research and development facility and testbed where everyone from engineers to architects can experiment with new ways of connecting up the world. There will be new methodologies and protocols from which the city of Bristol can be the first to reap the benefits.

The first aspect of the network to come online will be the dome. We’re guessing most *Focus* readers will probably have used Google Earth or Street View at some point. Well, now imagine being able to fly through a 3D rendering of a city, and zoom in on a particular building to pull up blueprints, wiring schematics and plumbing diagrams, or click on a particular street to see 3D-rendered, animated infographics describing the street’s demographics, air quality, crime rates or average daily

footfall. These are the kinds of advanced, highly intuitive ‘data visualisations’ that Bristol is Open and the data dome will make possible.

The planetarium’s 3D shows have been wowing audiences since April, and the first public demonstration of its data visualisation capabilities will take place on 18 November. *Focus* was lucky enough to attend an early demo back in August, and while this consisted simply of clips from the 3D planetarium show plus some 2D charts and maps, even that was mightily impressive.

Eventually, the system will be able to take information from external sources and render it in 3D in real-time, enabling all manner of data to be displayed in an easy-to-comprehend format. Its second media server (the first being a planetarium-specific system called Digistar 5) is based on open-source software and compatible with popular packages such as the Unity game engine, to ensure maximum accessibility for those who want to make use of it.

The dome will also be available for companies to lease out on a commercial basis – for 3D prototyping of new products, for instance. The client list remains confidential, but Rolls-Royce are already onboard and we do know that At-Bristol is talking to at least one major UK house builder. Such partnerships will provide Bristol is



Bristol is one UK city that will be testing driverless cars



IS BIG BROTHER WATCHING?

As soon as you start talking about big data – which is what Bristol is Open is really all about – it’s a small step, in many people’s minds, to Big Brother. With talk of sensor-equipped lamp posts and health monitoring via a state-controlled Internet of Things network, should Bristol citizens be worried?

Paul Wilson of Bristol is Open argues that they shouldn’t. “To anyone that’s worried I’d say: ‘What is it you think we’re able to do?’ We’re not seeing your phone, for example – unless you sign up to be part of something we don’t know anything about you at all. If you do choose to be part of some project, then yes, we might be getting some of your data. But it’s always an opt-in process.”

We already know that the NSA and GCHQ are tracking our internet use and reading our emails, and that Google, Apple *et al* know our whereabouts at all times thanks to the GPS transmitters called smartphones we carry everywhere we go. There’s not much Bristol is Open can do to add to that. So if you live in Bristol and were concerned that one day next year, someone’s going to flick a switch and see all the photos on your phone, and be able to disconnect your smart fridge if you haven’t paid your council tax... don’t be.

➔ Open with a valuable revenue stream, with the dome used for planetarium shows during the day, then hired out (when the council doesn't need it) as a data dome in the evenings.

"Then the next thing will be the mesh network," says Wilson. "That will launch in April 2016, and what that means is you can bring a device and see it in the network. That could be anything from a mobile phone or a fitness tracker, which is a small thing, to a driverless car, which is a big thing. It's going to be extremely useful as companies work to develop the Internet of Things, which is a key area of technological advance right now. Supposing you make 'smart' thermostats, for instance. We think there are around 10,000 such devices in Bristol. Currently we've got about four

hooked up to our network... but if you wanted to test how a network of 10,000 of them might be able to work together, we can help you do that."

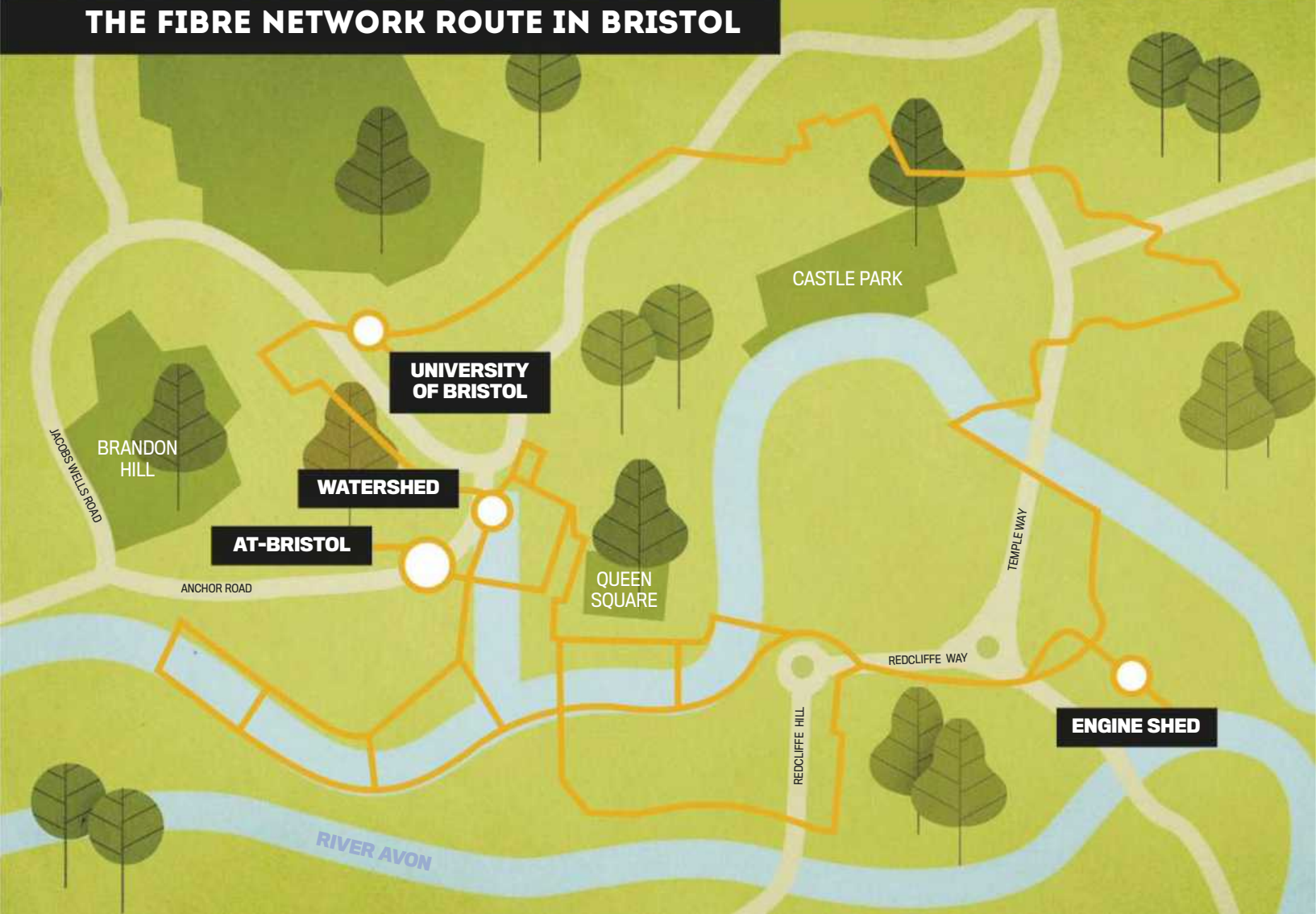
Looking at the mesh network from the city's point of view, there are also the lamp post sensors. "We'll be launching a project next year where we work with communities in Bristol, asking what problems they think exist in their area at an environmental level," says Wilson. "We don't know what those things will be yet – that's why there's a consultation process – but it could be air quality, it could be noise, things like that. And these are things we can put sensors in lamp posts for, so that we can monitor such situations on a city-wide basis, in real time.

"Litter bins are another example," he adds. "We could make every bin a smart

Right: At-Bristol science museum has the facilities to visualise data – like this map of the city's traffic



THE FIBRE NETWORK ROUTE IN BRISTOL





bin, so that the people in charge of sanitation know when they're full."

WHAT'S NEXT

Looking further forward, Wilson says he can imagine all kinds of uses for the Bristol is Open network – from linking cameras in lamp posts to the city's fleet of fire engines and ambulances so they can be sent to incidents before anyone's even dialled 999, to traffic management, to keeping an eye on the health of isolated elderly citizens, to monitoring pollution levels, carbon emissions and energy consumption (for more potential uses, see 'What can smart cities do?', right). The phrase that Bristol is Open uses is "building an operating system for the city". It's early days yet, admittedly – but these are the early days of what could turn out to be the next big leap forward.

"The *really* clever thing about our system is the way it's all managed and controlled," says Wilson. "That's where what we're doing is revolutionary – the rest is just sticking things in the ground and in lamp posts! At the moment, all the connectivity in networks is coupled in hardware, which is why if you switch ISPs, a man has to come to your house, take away your router and replace it with an identical-looking one from your new provider. But we're putting it into

software instead: that way, you have a technology-agnostic network, and with the click of a mouse, you can reconfigure the network and automate certain things. So we're able to provide connectivity on-demand wherever it's needed, whatever it's needed for."

"The way networks are built today," he continues, "they were never built for an Internet of Things, and they're already creaking. First we had physical computer networks, then dial-up over the phone, then broadband and mobile. But it's been built out in a very linear fashion, and is

constantly caught by surprise by the endless developments in technology. So what we're doing is having a fundamental rethink of how you build a network for the future world. Where there's a massive Internet of Things, and that leads you to build and manage the network in a completely new and different way. Our smart city here in Bristol will be one big use of that." ■

RUSSELL DEEKS is a freelance technology journalist, and Contributing Editor of *Focus*

WHAT CAN SMART CITIES DO?)))

The City of Stockholm owns a network of fibre optic cables that run below the city. This is used by the local authority as the backbone that enables a number of cost-saving and environmental initiatives, such as the Green IT project and the e-Stockholm service management programme, and also by industry and academia working together to develop new IT technologies in the Kista Science City.



In Santa Cruz, California, big data is helping to keep crime rates down. Computers analyse historical data to work out, at any given moment, the top 10 places a property crime is likely to occur. Police officers in the vicinity who are not engaged in an emergency are then automatically directed to patrol those locations. It's an example of how having large quantities of granular data can help improve local authority services.

The Amsterdam Smart City Initiative takes a different approach from the Bristol and Stockholm projects, in that it's all entirely wireless-based. There are over 70 different projects that make use of the network, including systems for traffic management and providing more energy-efficient street lighting, and 'serious games' linked to domestic smart meters that aim to educate youngsters about reducing energy use.





London's Hackspace lab looks pretty innocuous from the outside...

Amateurs are altering DNA as a hobby. So who are they, and what are they up to? **JV Chamary** meets the biohackers...

WITHIN A TINY room in a north London basement, Ilya Levantis opens a tupperware containing what looks like a leftover takeaway. “Fashion designers these days get interested in this stuff,” he says, proudly showing off a rubbery pancake in a brown liquid.

The “stuff” is kombucha, which is used to make fermented tea. It’s produced by a colony of microbes, the most important being *Gluconacetobacter*, which secretes strands of cellulose. Unlike material made by plants, a kombucha pancake is almost pure cellulose. When thin, it can be dried for paper, and used in wound dressings and high-end speaker cones. When thick, it’s tough enough for clothing. “Some people call it vegan leather,” says Levantis,

a 25-year-old graduate who works in bioinformatics. He can now do genetic engineering as a hobby.

Levantis is director of Biohackspace, a laboratory that’s half the size of a garage in

**“THE FIRST THING
I SAID WAS,
‘I WANT TO PLAY
AROUND WITH DNA
AND STUFF’”**

the London Hackspace – a building located, aptly enough, in Hackney. Some of the lab’s equipment was built using tools from the nearby electronics, woodwork and metalwork workshops, while other kit was donated by universities. Biohackspace

contains a PCR (polymerase chain reaction) machine that’s used for amplifying DNA samples, shelves of chemical reagents and a fridge full of Petri dishes – all the things you’ll find in a typical molecular biology laboratory.

Except the lab doesn’t cater for professionals, but amateurs. In March this year the UK Health and Safety Executive (HSE) registered Biohackspace as ‘GM Centre 3266’ – the first lab in the country that allows *anyone* to try their hand at genetic engineering.

Although many of us think ‘hacker’ means a person who breaks things (technically, that’s a ‘cracker’), the word more properly applies to people who make or repurpose things, especially those who tinker with technology. ‘Biohackers’ play with biotechnology and form part of the Do-It-Yourself biology movement.

DIY bio groups are run by volunteers, and members usually pay a monthly fee to cover the costs of facilities and supplies for a shared lab, which provides affordable access to anyone curious about biology. In 2010, there were only a handful of biohacking labs; according to diybio.org,

BIOCURI0US

*This enterprising
hackspace is bringing
DIY bio to Silicon Valley*

Back in the early days of modern computing, mavericks like Steve Jobs, Steve Wozniak and Bill Gates developed operating systems in a garage. The entrepreneurial spirit of early Silicon Valley continues in one of the world's leading DIY bio groups: BioCurious, which is based in Sunnyvale, California.

Since opening almost five years ago, BioCurious has welcomed everyone from entrepreneurs developing proof-of-concept products to high-school students working on their science fair projects. The group grows by two or three members every month, and currently includes anthropologists, physicists and software engineers.

One BioCurious community project on bioluminescence was spun-out as *Glowing Plant*, which raised \$485,000 on Kickstarter. *Glowing Plant*'s former lead scientist, Dr Kyle Taylor, now runs a 'plant research group' at BioCurious, where 15 members work on half a dozen projects.

Glowing Plant
was created by
a BioCurious
community



Prototype cell-washing machine (left) for removing salt so bacteria accept new DNA, and two bioreactors (right) for making biofuels etc



Before being dried, kombucha is a gooey, rubbery substance



Reagents used for growing cells include vinegar and seawater

there are now over 60 local groups around the world. While groups generally start as 'garage biology', others – like BioCurious in California – have become larger.

BRITAIN'S BIOHACKERS

London's Biohackspace currently has about 20 regular members from various backgrounds, ranging from artists to engineers. Most have no scientific training. Lena Asai, a design student at Goldsmiths, University of London, got interested after seeing biology-inspired art at a museum in her native Japan, where a scientist suggested she find a community lab. That led her to Biohackspace.

"They didn't know what to do with me in the beginning," explains Asai. "The first thing I said was, 'I want to play around with DNA and stuff'. Obviously I didn't know anything back then!" She has since attended a bootcamp at University College London (UCL) to learn basic genetic modification techniques. Her goal is to bring scientists and artists together. "We're not doing science just for fun," she says. "A communal lab is a great place

where we should initiate collaboration."

One of Biohackspace's collaborations involves the kombucha pancakes grown by Levantis. The liquid has added vinegar – to lower the pH for acidic culture conditions – plus food in the form of sugar, which can come from fruit juice. The team at Biohackspace wants to use the kombucha in a 3D-printing project called 'JuicyPrint'. While many 3D printers squeeze melted resin from a tube, depositing layers that turn solid after exposure to UV, JuicyPrint would use bacteria genetically-engineered to only produce layers of cellulose when blue light is shone on them.

Another project is a 'DIY Beer Kit', which aims to draw attention to hacking by exploiting the trend for home brewing. The kit includes a pick-and-mix of yeast strains, each genetically modified to make molecules that offer weird and wonderful flavours. Biohackspace entered its DIY Brew Kit in the 2015 International Genetically Engineered Machine (iGEM) competition, where it won a Bronze medal.

DIY bio and iGEM are closely linked to synthetic biology, which involves building living machines from a set of



Spin-out company Bento Bio is developing this 'lab in-a-box'



Kombucha being grown in an incubator



Biohackspace director Ilya Levantis (far right) discussing future plans with artist Lena Asai (centre) and other lab members

➔ standard parts – genetic Lego blocks called BioBricks. This requires a toolkit, and the most powerful new technique in molecular biology is the CRISPR-Cas9 system, known as 'CRISPR'.

CRISPRs (Clustered Regularly Interspaced Short Palindromic Repeats) are sequences of DNA letters, first discovered in *E. coli* in 1987. A decade later, researchers revealed that CRISPRs form part of an anti-viral defence system used by bacteria and other microbes: after a virus invades a cell, enzymes cut and paste bits of the viral genome between CRISPR sequences in the cell's DNA. This leaves a genetic memory for an RNA 'guide' that an enzyme called 'Cas9' uses to recognise and destroy viral DNA, should an invader return. In 2012, bioengineers showed that the RNA guide could be reprogrammed to target any DNA sequence.

Unlike most gene-editing techniques, CRISPR is revolutionary because the technology is precise. It's also quick, cheap and easy to use – so simple that even amateurs can use it. Johan Sosa, an IT consultant and member of hacking group BioCurious, is already experimenting.

"Currently we're creating the guide RNA that we're going to use to edit a yeast genome," he says. One possible application is the 'Real Vegan Cheese' project, which aims to modify baker's yeast so it produces milk proteins.

PLAYING SAFE

Anyone who tinkers with nature can be accused of 'playing God'. And given that some people are wary of genetic modification by professional scientists, it's understandable that some might worry about amateurs meddling with organisms they don't understand.

But even with CRISPR, we shouldn't overestimate what biohackers are capable of. "CRISPR is merely a tool – you still have to have an idea of what genes you want to turn on and off," explains Dr Darren Nesbeth, a synthetic biologist at UCL. "Knowledge itself is the biggest barrier to being able to redesign a cell."

Biohacking is also limited by the resources available to a typical DIY bio lab. Reagents such as enzymes can be expensive, and companies that

CRISPR

This powerful DNA editing technique is easy and quick – no PhD required!

1.



Scientists design a 'CRISPR' made from RNA. It includes a series of letters that matches a unique DNA sequence within an organism's genome.

2.



The CRISPR molecule is attached to 'Cas9' (shown here in beige). This is an enzyme that uses its RNA 'guide' to recognise the target DNA sequence.

3.



The CRISPR-Cas9 tool cuts the strands of the target DNA's double helix, then the cell's repair machinery will fix the damage – minus the old DNA sequence.

4.



The CRISPR technique can be used to delete unwanted DNA, or to find and replace a sequence by adding genetic material – such as a new gene.



A thin sheet of dried kombucha produces strong paper

manufacture CRISPR sequences have safeguards to ensure they don't supply potentially malicious genetic material. "Somebody can't order the sequence to build the Ebola virus," says Maria Chavez, Director of Community at BioCurious. "Nobody is going to sell you those genes."

Objections to biohacking are similar to arguments in the GM debate, which discuss hypothetical scenarios such as strains escaping, or terrorists designing weapons. Nonetheless, DIY bio groups take it seriously. US government agencies like the FBI and Department of Defense keep in touch and send agents to visit labs. "At the beginning they were coming through quite frequently – at least once a month, formally," says Chavez. "Informally, I'm not sure how many times they may have dropped in."

DIY bio groups also have rules for what their members can work with. BioCurious labs are classified at biohazard safety level-1 (BSL-1), which means no projects using mammalian cells. At Biohackspace, no pathogens are allowed. "They've got a licence now from the HSE to do genetic modification, which requires they have a

safety panel of individuals," says Nesbeth, one of the group's advisers. "There's a framework and guidance there equivalent to what happens at a university."

CITIZEN SCIENCE

Research has traditionally followed two routes – academic and industrial – but hobbyists could provide a third way. Such citizen science involves freedom from responsibilities such as teaching and writing scientific papers. It also offers a nice environment for brainstorming, but such blue-sky thinking is less tethered in reality, says Nesbeth. At Biohackspace meetings, he tries to bring members back down to Earth without being too negative. "So you have to avoid just being there to be a party-pooper and saying, 'Well, this will take millions of pounds,' or 'Actually, that will take 10 years'."

Nesbeth supervises UCL's iGEM teams and studies industrial applications for synthetic cells, such as manufacturing drugs and biofuels. He believes the biggest impact could be on altering the perception that genetic engineering is only done by

academics in an ivory tower. "I see it as a route to demystifying science for the general public," he says. Anyone can sign up to join their local biohacking lab.

At the end of Biohackspace's weekly Wednesday night meeting, several members take away sandwich bags containing kombucha to grow at home. Levantis mentions that because more people are getting involved in DIY bio, the lab now needs to expand beyond a basement in Hackney, a location which also makes it seem a bit hipster-ish.

"It's literally underground," Levantis jokes. "Our goal for the next lab is to have windows." ■

JV CHAMARY is a biologist and a writer. His latest book is *50 Biology Ideas You Really Need To Know*

DISCOVER MORE!



To watch Ilya, Lena and Victoria in an episode of *FutureProofing* on Radio 4, visit bbc.in/1KSRnRj

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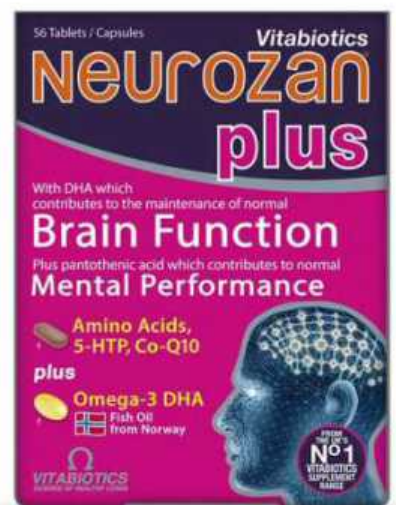
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ROBERT MATTHEWS

After studying physics at Oxford, Robert became a science writer. He's a Visiting Professor in Science at Aston University



GARETH MITCHELL

Starting out as a broadcast engineer, Gareth now writes and presents *Click* on the BBC World Service



LUIS VILLAZON

Luis has a BSc in computing and an MSc in zoology from Oxford. His works include *How Cows Reach The Ground*

EMAIL YOUR QUESTIONS TO questions@sciencefocus.com

or post to *Focus Q&A*, Tower House, Fairfax Street, Bristol, BS1 3BN



Q TINA HANSON, LITTLEHAMPTON

How do waterfalls freeze?

A WATER TURNS TO ice when its molecules move slowly enough to form rigid bonds. Normally, the molecules in the waterfall move under the influence of both the flow and thermal agitation. But if it gets cold enough, the heat effect becomes so low that not even the waterfall's motion can stop ice forming, gradually at first but then ever more rapidly. **RM**

PHOTO: GETTY



Perhaps if they all
blow really hard,
that will help too?

Q GEORGE JEFFRIES, ST ALBANS

Can a yacht ever travel faster than the wind?

A THIS SEEMS LIKE defiance of the laws of physics, but it just needs the right shape and size of sail to trap enough of the air-mass blowing in the wind. The resulting transfer of momentum can propel yachts to impressive speeds, especially if friction is minimised – some sleek catamarans can achieve 80km/h using 35km/h winds. **RM**

Q PAUL LESLIE, CHELMSFORD

On average, how many of our muscles do we use regularly?

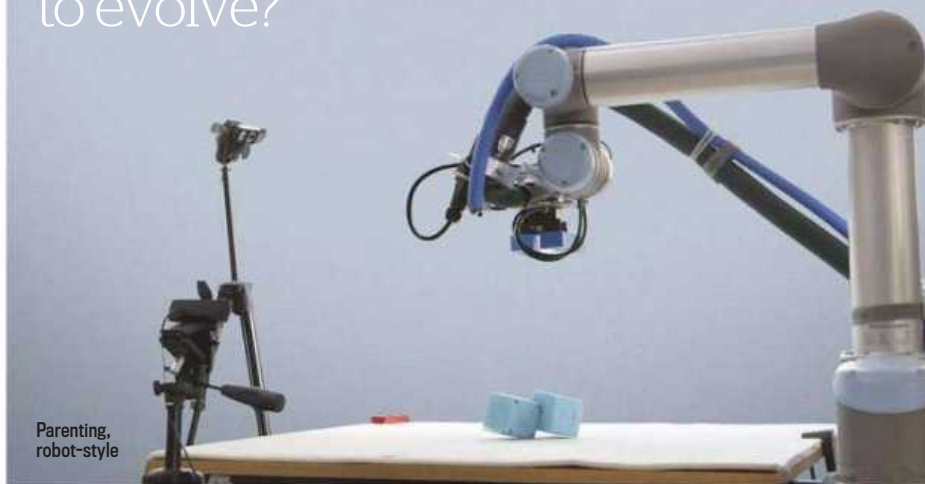
A JUST ABOUT ALL of them! But our least-used muscles are probably the lumbar multifidus muscles in the lower back. Studies have shown that prolonged slumping in front of the TV can inactivate these muscles. This can lead to back pain, and once inactivated they can take months to recover. **LV**



We're not convinced
that a 5kg barbell
gave him those biceps

Q TIM ROBERTS, LEICESTER

Could robots be programmed to evolve?



Parenting,
robot-style

A YES. IN RESEARCH that was published in August this year, teams in Cambridge and Zurich built robots that evolve through successive generations.

The 'mother' is a robotic arm that builds 'baby' robots out of small cubes. Each cube has a mechanism where one side can waggle. When you place it on a surface, it clumsily drags itself around. The mother glues these moveable cubes together in various arrangements. Some combinations move further and faster than others. The mother robot builds each arrangement

using assembly instructions in the form of a 'genome' that is passed between successive generations of robots.

The mother is programmed to insert random mutations into each generation. Some offspring move around better than their forerunners, but others do worse. The mother rejects deficient generations but uses the genetic blueprints of successful ones to build subsequent offspring. In the lab, after only 10 generations, the robots performed twice as well as those at the start of the process. **GM**

Q JON INGRAM, GATESHEAD

Could we exist on Earth under a red giant star?

A ABOUT FIVE BILLION years from now, the Sun's usual source of nuclear energy will be depleted. It will begin to expand and cool significantly, becoming a 'red giant'. Its outer layers will be thrown off into space. As the Sun loses mass, its gravitational pull will weaken and the planets' orbits will widen. We know that Mercury and Venus will not be able to outrun the expanding Sun, and will be engulfed and incinerated.

Earth may just outrun the swelling red giant but its proximity, and the resulting rise in temperature, will probably destroy all life on Earth, and possibly the planet itself. However, there's no reason that life could not survive on another planet (or moon) sufficiently far out from the Sun, as long as it lies within the Sun's expanded 'habitable zone'. Life could also survive on suitably hospitable planets around other red giants. **AG**

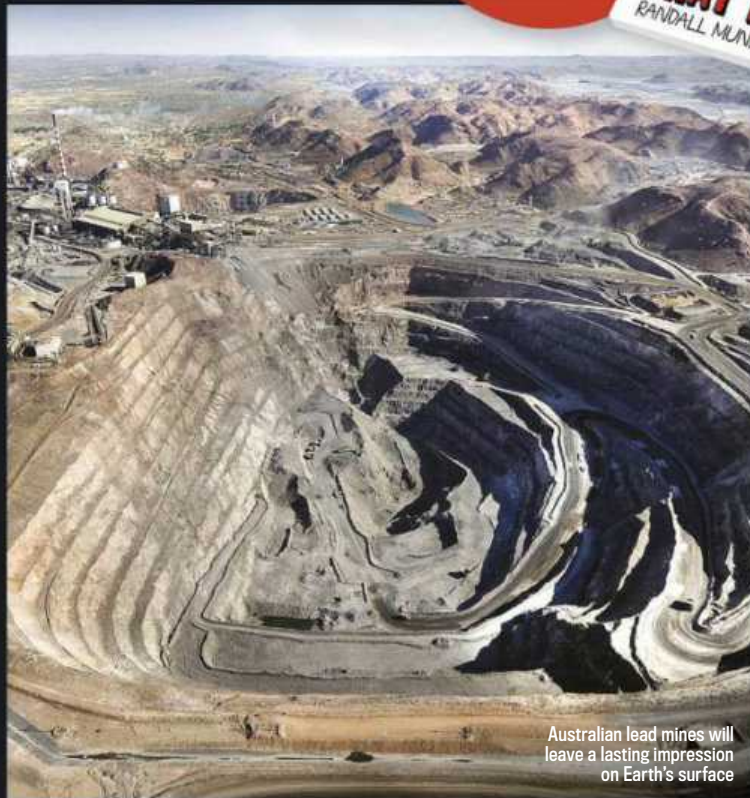
The future's so bright, we're all going
to die horribly in a stellar inferno



QUESTION OF THE MONTH

WINNER!

Congratulations to Malcolm Douglas who wins *What If?* by Randall Monroe (John Murray, £7.99)



Australian lead mines will leave a lasting impression on Earth's surface

Q MALCOLM DOUGLAS, DUBLIN

If humans became extinct, how long would it take for all traces of us to vanish?

A STONEHENGE IS AT least 4,000 years old and still visible today, and monuments buried nearby could be even older. Most modern buildings aren't that robust, but some traces would likely remain for at least 10,000 years, even if it was just the magnetic trace of the steel bars inside concrete blocks. When Hong Kong Airport was constructed in the 1990s, the island of Chek Lap Kok was flattened and extended, and the straight edge of its northern coastline will be a clue to our civilisation for tens of thousands of years. Our atmosphere also

has high levels of plutonium-239 due to nuclear weapons testing during the Cold War. This isotope only occurs in nature in incredibly small amounts, and will be detectable as a pollutant for at least 250,000 years.

But the most enduring signs of civilisation will probably be deep mines in hard rock, such as South African gold mines and Australian lead mines. Here, visiting aliens would be able to see signs of our civilisation for millions of years, as the tunnels fill up with sediment washed down by rainwater to create massive industrial 'fossils'. **LV**

Giraffes' necks are an evolutionary puzzle



Q SALLY ELLIS, MANCHESTER

Aren't epigenetic effects evidence for Lamarckism?

A NOT REALLY. EPIGENETICS is when genes alter their activity in response to external factors such as diet, exercise and chemical exposure. The sequence of letters in the DNA doesn't change, but the DNA molecule acquires other chemical changes that can be passed on to your offspring. These inherited traits last for two or three generations.

Lamarckism says the giraffe got its long neck because parents stretched their own necks slightly during their lifetimes and passed that increase on to their children, and so on. That's quite different from the Darwinian view that each generation has a certain amount of natural variation, and that giraffes with longer necks have more offspring. Epigenetics is an important influence on evolution, but it doesn't drive long-term species change. **LV**


In Numbers

0.325mm

is the size of the world's tiniest free-living (non parasitic) insect - a featherwing beetle

TOP 10

FASTEST FISH
IN THE OCEAN

- 
1. **Black marlin**
Maximum speed: 129km/h
Range: Australian coast and tropical Indo-Pacific
 2. **Sailfish**
Maximum speed: 110km/h
Range: Indian and Pacific Oceans
 3. **Striped marlin**
Maximum speed: 80km/h
Range: Tropical and temperate regions of Indo-Pacific Ocean
 4. **Wahoo**
Maximum speed: 78km/h
Range: Tropical and sub-tropical waters around the world
 5. **Mako shark**
Maximum speed: 74km/h
Range: Tropical to temperate waters worldwide
 6. **Atlantic bluefin tuna**
Maximum speed: 70km/h
Range: Open waters of the Atlantic Ocean
 7. **Blue shark**
Maximum speed: 69km/h
Range: Deep waters of temperate and tropical oceans
 8. **Bonfish**
Maximum speed: 64km/h
Range: Shallow, inshore tropical waters
 8. **Swordfish**
Maximum speed: 64km/h
Range: Tropical and temperate waters of the Atlantic and Indo-Pacific
 10. **Fourwing flying fish**
Maximum speed: 56km/h
Range: Subtropical waters of the Atlantic and Pacific

Q STELLA RODGERS, WHITLEY BAY

How do astronomers measure the size of planets?



A THERE ARE SEVERAL ways that planetary diameters can be measured. The most common is to measure the apparent angular diameter of the planet – how big it looks against the sky – very precisely using a telescope. Combining this with a measure of its distance

(deduced from its orbit around the Sun) reveals the planet's actual size. Another method involves studying the motion of moons as they eclipse the planet. Some accurate values of diameter, for example for Venus, come from radar observations from space probes in orbit. **AG**

Q CHARLIE MACK, UCKFIELD

What was the life expectancy of a dinosaur?

A SCIENTISTS CAN MEASURE the age of some dinosaur species from the growth rings inside fossil bones, much as you can tell the age of a tree by the rings inside its trunk. The oldest known *Tyrannosaurus rex* specimen, this method tells us, was 28 years old when she died, by which age she was fully grown.

But this technique doesn't work well on many species, because their bones grew continuously and don't have neat growth rings. Early estimates of 300-year lifespans for the largest sauropods were based on comparisons with crocodiles and turtles, which have much slower metabolisms. The consensus is now that *Apatosaurus* and *Diplodocus* dinosaurs probably only lived for 70 or 80 years, which is about the same as an elephant today. **LV**



Apatosaurus lived around 150 million years ago

Q CAROLINE O'BRIEN, LONDON

Why do people cheat?

A BECAUSE THEY WANT to win the easy way. As competitive animals, we human beings constantly seek out opportunities to gain money, food and sex, or simply to look good. Doing all this the hard way requires expenditure of time, effort and energy, so cheating can obviously be very tempting.

Evolutionary game theory has helped to explain how altruism can exist alongside cheating. Generally, cheats do well when they are rare, but less well when they are many and have fewer non-cheaters they can exploit. So groups tend towards an equilibrium, with few enough cheats that it's not worth the cost of stopping them. Sadly, this basic biological principle means we are unlikely ever to be completely free of cheats. **SB**



Steroid use cost Ben Johnson his 1988 Olympic gold medal

WHAT IS THIS?



KNOW THE ANSWER?

Submit your guess now at sciencefocus.com/qanda/what

LAST MONTH'S PICTURE

Michelle Robertson correctly guessed a hairy bittercress seed pod



Q FINN CROZIER, OSWESTRY

How exactly does electricity kill you?

A AT LOW CURRENTS, AC electricity can disrupt the nerve signals from the natural pacemaker in your heart and cause fibrillation. This is a rapid fluttering vibration, too weak to pump blood. If the rhythm isn't restarted with a defibrillator, it's usually fatal. At higher currents, DC electricity can have the same effect by causing the entire heart muscle to contract at once, which also breaks the pacemaker rhythm. The highest currents (more than one amp) cause burns through resistive heating as the current passes through the body. If this path crosses the heart or brain, then the burn may be fatal. **LV**

In the event of low-flying arrows, do the limbo



Q JAMES SLATTER, FELTWELL

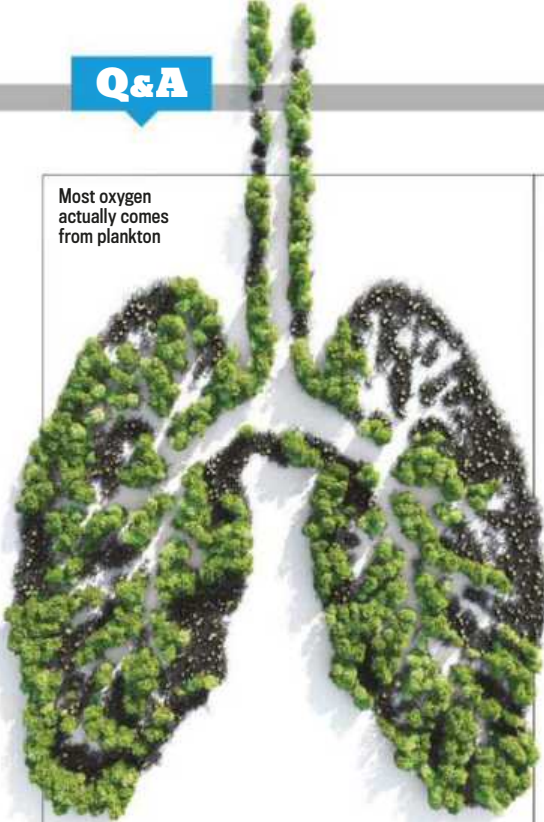
What dictates where branches grow on a tree?



The hormone auxin controls how tree branches grow

A AS THE TRUNK grows upwards, buds are produced on either side. These buds are initially dormant because the growing tip at the top, called the 'apical meristem', produces the hormone auxin, which inhibits their development. Once the apical meristem has grown far enough away, the concentration of auxin near the bud drops and it can begin growing sideways. This sideways shoot also lays down its own buds, which are in turn kept dormant until the shoot's own growing tip has advanced enough. **LV**

Most oxygen
actually comes
from plankton



Q RICHARD HARRISON, FIRBECK

How does Earth maintain a constant level of oxygen?

A IT DOESN'T! THE oxygen level of the planet has varied quite dramatically in the last 500 million years. It was 35 per cent during the Carboniferous period, around 300 million years ago; as the climate cooled and land plants died off, oxygen fell to as low as 12 per cent by the beginning of the Triassic. Back then, the air at sea level would have felt thinner than at the top of the Alps today.

Burning fossil fuels has reduced oxygen levels very slightly – about 0.057 per cent over the last 30 years. Deforestation only has a small effect because when rainforest is cut down, other plants are usually grown in its place. But it's marine plankton, rather than trees, that produces about 70 per cent of atmospheric oxygen. Global warming will have a significant impact on plankton, which is a much more serious threat to oxygen levels. **LV**

In Numbers

48million

is the age in years of a 12.5cm-long fossilised foetus being studied in Germany. The specimen is thought to be an early horse-like species

Q LIZZIE REES, EDINBURGH

Is crying good for you?

A MANY PEOPLE WOULD say yes. Crying is said to be cathartic, relieve stress and even remove toxins from the body, and most therapists claim it's beneficial. There is evidence that blood pressure and heart rate fall after crying, while some allergic reactions are reduced after watching weepy films, and sufferers from rheumatoid arthritis who cry have less pain than those who don't.

Yet the experimental evidence is mixed. Benefits are more likely when the reason for crying is a resolvable problem and the person crying is comfortable expressing their emotions and not otherwise depressed. One function of crying may be to show our distress, which can help build relationships, and this may be why crying helps. **SB**



Q ROB HARPER, LONDON

Could an asteroid impact push the Moon closer to us?

A THE MOON IS very big, and any small object hitting it would have very little effect on its motion around the Earth, because the Moon's own momentum would overwhelm that of the impact. Most asteroid collisions would result in large craters and little else; even the largest asteroid known, Ceres, wouldn't budge the Moon.

However, if an object of similar mass and velocity to the Moon were to hit it, the Moon's orbit could well be altered, though it's more likely the Moon would be destroyed by such an impact. If the Moon were to orbit closer to Earth we would experience much larger tides, along with longer and more frequent solar eclipses. **AG**



No satellites were harmed in the making of this picture



HOW IT WORKS

THE DRINKABLE BOOK

EVERY YEAR, OVER 3.4 million people die from problems associated with water, hygiene and sanitation. It's a huge problem, because the vast majority of individuals who live in areas with dirty water don't even realise that it's unsafe to drink.

To try to solve the issue, Dr Theresa Dankovich created a special type of bacteria-destroying filter paper for her PhD at McGill University. She's now based at Carnegie Mellon and has teamed up with scientists from

her current institution and the University of Virginia to create The Drinkable Book.

Once water has been passed through a page of the book, it comes out on the other side with a 99.9 per cent reduction in bacteria, which makes it comparable to tap water in the USA.

It works because each page is coated with silver nanoparticles, which are capable of destroying bacterial diseases such as *E. coli*, typhoid and cholera. Each filter can offer 30

days of clean water – up to 100 litres – and each book can last for up to four years.

The text printed on each page of the book helps educate people about water safety, by explaining the importance of keeping rubbish and human waste away from the water supply. So far, the filters have been trialled successfully in the developing world. However, at present, the papers are not capable of destroying other organisms, such as protozoa and viruses.

The book comes printed with guidelines for safe water consumption both in English and local language



1 Tear out a page, insert into a filter holder issued with book

2 Pour dirty water through filter

3 Silver ions – positively-charged particles – interfere with a bacterium's metabolism, producing substances called reactive oxygen species (ROS)

4 ROS damages the membrane that surrounds a cell, as well as the DNA and proteins. Bacterium dies



Q MIKE SHELBY, READING

Is it true that dogs can detect cancers?

A STORIES ABOUT DOGS warning their owners of early signs of cancer have been circulating for years. Now hard scientific evidence is emerging to back the idea – at least for trained dogs. Studies involving dogs exposed to samples of breath, urine and other body fluids from cancer patients suggest they can detect the presence of lung, colorectal and prostate cancer, among

others. In some cases, the dogs outperform standard lab tests, achieving higher detection rates and fewer false alarms.

Researchers believe the dogs' highly refined sense of smell can detect the volatile organic compounds produced by malignant cells. However, a recent review of the evidence cautioned that it's still unclear whether the dogs can pick up signs of cancer early enough to be useful. More research is needed, and a major UK trial of the ability of dogs to detect breast cancer in breath samples from 1,500 women is currently underway. **RM**



Dogs have proven especially good at detecting tumours wrapped in bacon

Q RICHARD HOUSE, NORTH YORKSHIRE

Why do we have moles on our skin?

A DURING THE FIRST 12 weeks of pregnancy, the developing foetus is making melanocytes – the skin cells that produce ordinary skin colour. These aren't always evenly spread out: random areas will acquire a cluster and during your life, these clusters can grow into a mole.

Moles are quite different from freckles. Almost everyone has from 30 to 60 moles on their body, but freckles only occur in people with certain genes – particularly the one responsible for red hair. Freckles also need sunlight to trigger them, while moles appear spontaneously. **LV**

Q JONATHAN LLOYD, TELFORD

Why is it colder at the top of a mountain, if you're closer to the Sun?

A AS THE SUN is around 150 million kilometres away, even being on top of Everest only brings you 9km closer – far too small a difference to make you feel any warmer. The distance effect is totally overwhelmed by that of having less atmosphere around you as you climb. This leads to a steady fall in atmospheric pressure, and – as the air isn't so compressed – a fall in

temperature as well. The rate of decline is surprisingly fast: around 1°C for every 100m, and continues all the way up to the so-called tropopause around 12km above the Earth.

At these altitudes, barely 10 per cent of the atmosphere remains, and the air pressure is so low that the temperature falls to a lethally cold -55°C. The threat is not academic, either: at any given

time, hundreds of thousands of people are being transported at these altitudes aboard aircraft. Passengers and crew are kept warm using hot air taken from the compressor stages of the engines before it's mixed with fuel. This, combined with insulation in the walls and heat generated by the passengers themselves, ensures the cabin can be kept at room temperature. **RM**

The Sun won't warm you up if atmospheric pressure is low



Q CHARLES HILLS, EXETER

Why do bees die after stinging you?

A HONEY BEE STINGS have a barbed ratchet mechanism that pulls the stinger into the initial wound. This didn't evolve as a suicide mechanism – honey bees can pull their stings out after stinging other insects. It's meant to drive the stinger in as deep as possible; it just happens that mammal skin is too fibrous to release the sting, so the abdomen is torn open when the bee tries to escape afterwards. Honey bees are the only species to suffer this fate, but the cost to the hive of losing some workers is worth it for an improved ability to repel honey thieves. **LV**



This pollinating insect has passed on. He is no more. He has ceased to be

Q PEARL GOODWIN, LEWES

Why does time go so fast when you're asleep?

A DOES IT? GENERALLY this is not true, and most people are good at judging how many hours they've slept. Some can even tell themselves to wake up at a specific time and do so. Time perception can be distorted, though, and experiments show that estimates are generally good, but people tend to overestimate time passed during the early hours of sleep and underestimate during the later hours. Time estimations during dreaming are much more variable and some people claim to have dreamt a whole lifetime in one dream. However, the best experiments to test this come from those very rare people who can induce lucid dreams (knowing they are dreaming) at will, and then signal to experimenters to indicate what they are doing in the dream. When asked to count to 100 while dreaming or while awake,

the times taken match closely. And when asked to estimate how long a dream event took, those estimates are accurate. So if time does go fast when you are asleep, you are unusual! **SB**

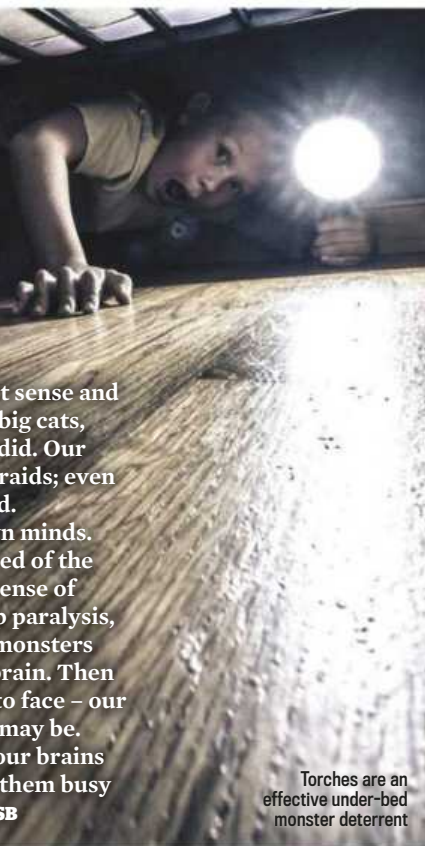


Q ERIC TAYLOR, BY EMAIL

What makes people afraid of the dark?

A LOSS OF VISION. Sight is our strongest sense and some of our natural predators, such as the big cats, had better night vision than our ancestors did. Our ancestors also had to watch out for enemy raids; even today, we may justifiably fear being burgled.

But our greatest fears come from our own minds. Many children, and some adults, are terrified of the monster under the bed. This is called the 'sense of presence' and is often associated with sleep paralysis, when you wake up unable to move. These monsters are due to unusual activity in areas of the brain. Then there are all those ideas that we don't like to face – our shame, guilt, anger, anxiety or whatever it may be. These seem far worse in the dark because our brains are deprived of the visual input that keeps them busy and suppresses those unwanted thoughts. **SB**



Torches are an effective under-bed monster deterrent

Q ROB RICHARDS, CIRENCESTER

Can computers make mistakes?

A COMPUTERS DON'T MAKE mistakes, as such, but they can make errors. When your laptop crashes, it has gone into an error condition where it fails to run the computer code effectively. If anything, the 'mistake' is that of the human who produced ineffective code or faulty hardware. Or it's a simple case of the user asking the machine to perform a task that's outside its normal operational envelope. **GM**





Q THERESA LOWRY, CARDIFF

Why do little girls like pink?

A PROBABLY BECAUSE OF social pressure. In Britain and the USA, older girls like pink more than boys do, but they could already have been influenced by expectations. So studies have tested one- to two-year-olds by

using the 'preferential looking task', which measures what the children like to look at the most. The studies found that preferences for toys differ by sex, with boys looking longer at cars and girls at dolls, but preferences for colour

do not. So perhaps it's not surprising to learn that back in 1918 the trade publication *Earnshaw's Infants' Department* wrote that babies' clothes should be pink for a boy and blue for a girl. **SB**

Q CAROLINE MAY, BRISTOL

What's the longest an animal can survive without oxygen?

A MANY SPECIES OF bacteria and protozoa don't need oxygen at all, and in 2010 researchers also found three new species of microscopic multicellular animals that can survive without oxygen, living in the seabed mud of the Mediterranean Sea.

All vertebrates need at least some oxygen, but the record for holding

their breath goes to the endangered desert pupfish *Cyprinodon macularius*. This 7.6cm fish has evolved to randomly switch its metabolism over to an alternate pathway that doesn't use oxygen and produces ethanol as a byproduct. They can survive like this for up to five hours at a stretch. **LV**

The desert pupfish is restricted to just a few sites in the US and Mexico



PHOTO: GETTY X2

Q MARY BROOKS, TOTNES

Why do live events transmit faster to my digital radio than my TV?

A DIGITAL AUDIO OR video is transmitted as a series of binary bits. Like a dam holding back water in a stream, broadcast equipment stores up a backlog of data. Then, if there are dropouts in transmission, there's a sufficient supply to maintain the signal without interruption. Some services buffer more than others, explaining the discrepancy between digital radio and digital TV. **GM**

NEXT MONTH Over 20 more of your questions answered

For even more answers to the most puzzling questions, see the Q&A archive at www.sciencefocus.com/qanda

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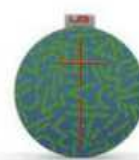


Insanely great sound and deep-powerful bass blasts in every direction.

Dirt and waterproof, the UE BOOM 2 is ideal for any festive celebration. Throw it on your bike, clip it to your bag or just grab it and go – get it wet, get it muddy, stick it in the snow for the ultimate 'chill out', or cover it in mulled wine during the wee hours – nothing will stop the music pounding.

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PERFECT GIFT FOR THE HOME OFFICE

iiyama ultra slim IPS displays are ideal for the office and discerning gamer

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multi-monitor applications for today's increasing demands for displaying more data from multiple sources. iiyama have a philosophy of manufacturing user friendly products. As standard these products come with an ergonomic height adjustable stand which pivots into portrait mode. Furthermore, these

stunning displays are topped off with speakers and a head phone connection and offer a reassuringly low power consumption, conforming to the latest Eco standards. iiyama Ultra Slim LCD display are a gift of choice this year, even if you are simply treating yourself to an upgrade.



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CURIOUS ABOUT VIRTUAL REALITY?

2016 will be all about VR, but for those curious now there is an affordable headset that uses your existing phone to anchor you into stunning immersive environments



Proteus VR spent 18 months designing and tweaking the Freefly with one agenda – to prove mobile virtual reality could be just as compelling as its PC-based cousins, without the wires and high price-tags.

Iceland's Björk selected the Freefly to launch her first VR music video – Stonemilker, at MoMA in New York and Rough Trade Records in London.

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Web starcraft.com

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StarCraft II: Legacy of the Void is available online at www.starcraft.com. Previous versions of StarCraft II are not required to play.





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Skill is essential, but the right tool is what puts a dedicated gamer over the top. Combining amazing technical engineering with savvy, eye-pleasing design, the ROCCAT® Isku FX Multicolor Gaming Keyboard offers you supreme quality, precision command, and a bold, uniquely ROCCAT design. The Isku FX is the complete package. Now available in a stylish white design.



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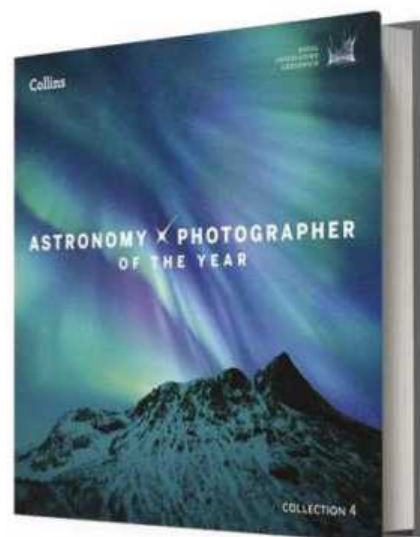
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CHRISTMAS GIFT GUIDE



MEADE INSTRUMENTS

Distributed by Hama

Meade Polaris 130EQ Telescope SRP: £200

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Meade Infinity 90AZ Telescope SRP: £210

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Stuff

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T3

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HiFi News


"This company single-handedly taught the world that there is life beyond the iPod and iPhone for music on the go"
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The Mail on Sunday**

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THE FUTURE OF GADGETS

TECH HUB

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p99

THE ULTIMATE
CHRISTMAS
WISHLIST

Please, Santa,
we've been good!
p101

EDITED BY **RUSSELL DEEKS**

ON THE HORIZON

ROBOHON


It's a robot! It's a smartphone!
It's almost unbearably cute!

robohon.com/special/english

APPLE, MICROSOFT, GOOGLE... stop what you're doing right now! You've been getting this 'intelligent personal assistant' business all wrong. The way forward isn't putting a quasi-human persona à la Siri, Cortana *et al* inside a smartphone; the way forward is putting a smartphone inside a quasi-human shell or, to be more precise, inside a humanoid robot pal that makes Brian from Confused.com look positively surly.

At least, that's what Sharp is banking on as it unveils Robohon, a 19cm-high robot-shaped smartphone that talks to you. Just to be clear, this isn't some futuristic prototype built to wow the crowds at trade shows. It's an actual, working consumer product, and it's going on sale in Japan early next year. And to say it's dividing opinion in the tech world would be an understatement.

In the blue corner, we have serious-minded, utilitarian commentators whose basic reaction is, "Why the hell would I want one of those? What on Earth was Sharp thinking?" Such commentators point to the phone's tiny, rear-mounted screen, and to Sharp's promo video which – somewhat unrealistically, they suggest – features someone climbing a rock face with Robohon swinging merrily from their chest in a papoose. In their eyes, Robohon can be written off as a cutesy gimmick that's doomed to failure anywhere outside Japan.

Over in the red corner, meanwhile, we have the rest of the human race, whose reaction to seeing the Robohon video is generally 





Robohon acts as a personal assistant and can even bust some moves too

→ something along the lines of: “OMG that’s the best thing I’ve ever seen! When can I get one?” When it comes to the battle for hearts and minds, there may be a lot of minds to win over but hearts belong to Robohon, no contest.

As cute as Robohon is, there’s also no denying that the ‘blue’ commentators have a point. Several points, in fact. At a time when smartphones are looking more and more like tablets, while tablets increasingly come with detachable keyboards that turn them, essentially, into laptops, equipping Robohon with a mere two inches of display seems an almost insanely backward step. How’s that supposed to compete with the 4K screen on the Sony Xperia Z5 Premium, which featured on these very pages last month?

Robohon’s quad-core 1.2GHz CPU sounds reasonable enough, but lags behind the likes of the Samsung Galaxy Note 5, which boasts a quad-core 2.1GHz processor. Perhaps most concerning of all, though, is just how little Sharp is actually telling us about Robohon’s inner workings – it hasn’t even said what operating system Robohon will run on. The internet rumour mill suggests some flavour of Android, even if it’s a Sharp-customised version, but – sorry to break it to you like this – the internet rumour mill has been known to be wrong on occasion.

Combine somewhat middling known specs with the general air of mystery surrounding the launch, and it’s not surprising that more cynical observers are doubting whether Robohon will have the performance chops to overcome the fear of

looking foolish because you’re walking down the street talking into a child’s toy.

On the other hand... just watch the video. If you hate the thought of being woken up by a robot cheerily calling out ‘Morning! It’s time to wake up!’; if you don’t like the idea of a personal assistant who at your command will bend at the waist to project your photos onto the nearest available surface; and if you can’t see the benefit of having a phone that talks to you, learns from you and, for the love of Mike, even dances... if you can’t imagine these things bringing joy into your life, then you’re probably the kind of person who sees a litter of tiny, fluffy kittens and thinks ‘hacky sack tournament’.

With no word yet as to exactly when Robohon will go on sale in Japan, how much it will cost, or whether it will ever be made more widely available, we’ll just have to wait and see how the phone manages as a commercial proposition. But we’re undoubtedly moving towards a future where robotics and artificial intelligence play an ever-increasing role in all our lives. With Robohon, Sharp is exploring new ways in which humanity and all that technology might interact.

And for that, the company should be applauded, not ridiculed. After all, in 1999, Sharp introduced the first mobile phone with a built-in camera – to which many commentators’ reaction at the time was, “Why the hell would I want one of those?”

RUSSELL DEEKS is a freelance technology journalist, and Contributing Editor of *Focus*

TECHOMETER

WHAT’S HOT

8K DISPLAYS

Neither the public nor the TV industry has exactly rushed to adopt 4K resolution: no UK TV channels broadcast in the format, and there’s only limited content on Netflix and YouTube. But that hasn’t stopped manufacturers cracking on with 8K cameras and screens. The format is intended for use with large screens, with the first commercially available 8K screen – an 85-inch Sharp model – now on sale.



WHAT’S NOT

You may have seen people riding Swegways – self-balancing electric scooters that look like a Segway without handlebars. But they look like becoming The Craze That Never Was, because the UK’s Crown Prosecution Service has declared their use illegal both on pavements and on public roads, citing safety concerns.



READER POLL

Would you use a Robohon?

50% Yes – that’s what I call an Android phone!

50% No – does not compute!

THE NEXT BIG THING

ARE WE ALL CYBERWARRIORS?

Our online security is being compromised

LIKE EVERY OTHER internet user, I rely on decent encryption to make life online possible. Every time I connect to a secure server, such as my bank, a complex dance takes place between my computer and the server involving a choice of random numbers, a lot of processing and the exchange of encryption keys.

The result is a secure channel between us. At least, it's supposed to be, because one consequence of the slowly-simmering cyberwar between nation states is that the *actual* security of almost every network connection is being compromised in the interest of *national* security. The future of online life is starting to look more and more like living in a divided and threatened city, not the peaceful metropolis we were promised.

Evidence has recently emerged to indicate that the US National Security Agency is spending a lot of money on a system that can break public key encryption because of a poor implementation in some of the main offerings. This isn't a problem with the maths, but with the way the software has been written.

Security agencies have also been keeping quiet about security flaws in popular software, using them instead to get access to information from targets. Sadly, it's highly likely that other people – such as criminal gangs, hackers and the odd unfriendly nation – are also aware of these bugs, and are exploiting them for less noble purposes. By keeping quiet, we're left more at risk.

This is just one aspect of cyberwar, of course. More and more physical hardware, from thermostats to watches through to power stations, dams and even oil refineries relies on computer systems to operate. The recent chilling discovery that you could hack into the entertainment system on a Chrysler Jeep and use it to control the steering and brakes may have been a security flaw, but it's the sort of flaw that cyberarmies will be looking for – it's easier to disable a tank over a network than fire an armour-piercing missile accurately.

War used to be confined to a particular geographic area. If you lived there, it was hell and you were in enormous danger, but populations away from the war zones could carry on with



Though cyberwarfare is mostly waged between nation states, the repercussions affect us all

their life. Aerial bombing, such as the London Blitz and the US action in Cambodia changed that, and the development of nuclear weapons and intercontinental missiles put us all at risk of mutually assured destruction.

Now the zone of engagement has extended online, and it seems that life on the internet is going to be more like living in North Korea than northern California when it comes to

the assumptions we can make about our safety, security and freedom from surveillance. I'd prefer an internet that wasn't weaponised, but it may be too late to get the cybersoldiers to back down.



BILL THOMPSON contributes to news.bbc.co.uk and the BBC World Service

FROM THE LAB GRAPHENE PRINTING

WHAT'S GOING ON?

A team led by Dr Tawfique Hasan at the Cambridge Graphene Centre has developed a new way of printing using graphene-based ink. Although several graphene printing methods have been demonstrated before, Hasan's team is the first to achieve the kind of printing speeds that will be needed for the process to become commercially viable.

HOW DOES IT WORK?

Tiny particles of graphene are suspended in a 'carrier' solvent mixture, which is then mixed with conductive, water-based ink. The printed material's resistance can be controlled by varying the ratio of the ingredients, and the same method could also be used to create inks based on other types of metallic, semiconducting or insulating particles.

WHY IS IT USEFUL?

Currently, most printed circuits are made from a mixture of carbon and silver. By substituting graphene ink, such circuits could be printed more quickly, would be less harmful to the environment and would be up to 25 times cheaper to produce. Suggested applications include the production of 'intelligent' packaging and disposable biosensors.



Graphene ink could allow the cheap production of smart labels

**Urgent call for help to save the eastern lowland gorilla issued by Fauna & Flora International.
Your response by 14 December could help protect the remaining gorillas.**

Photo: Simon J. Child/Intergalactic Gorilla Productions



Without action now the eastern lowland gorilla could be gone forever – cut the coupon or go to www.savegorillas.org.uk to help protect the remaining gorillas.

One of the world's rarest apes faces extinction

Population plummets from 17,000 to less than 10,000

Consumed by conflict and caught in the grip of a severe conservation crisis, the eastern lowland gorilla – the world's largest gorilla – is fighting for survival.

Fauna & Flora International (FFI) has put out an urgent call to the global community to save the remaining 10,000 or so eastern lowland gorillas.

Funds are sought immediately to help protect new community nature reserves that are essential to the survival of the remaining gorillas between the Maiko and Kahuzi-Biega National Parks in the Democratic Republic of Congo (DRC). It is a crucial step towards protecting these elusive and Endangered apes from complete extinction.

The eastern lowland gorilla faces multiple threats to its survival – all of them due to human activity. A major expansion of agriculture and pastures in the DRC in recent years has put enormous strain on the gorilla's shrinking habitat. Industry, too, has taken its toll, with natural habitats squeezed by extensive mining for gold and coltan – a mineral used in making mobile phones. Hunting and the continuing consumption of illegal 'bush meat' have also caused many apes to be killed. What's more, continuous conflict has made it incredibly challenging to enforce wildlife protection.

As a result, numbers of eastern lowland gorillas have plummeted. Just 15 years ago there were around 17,000 eastern lowland gorillas in the wild. Today, scientists believe that at most 10,000 may still remain alive. Experts don't know for sure exactly how many there are, but scientists are carrying out population surveys to find out exactly how low the gorilla population has dropped. The critical conflict problems in the DRC mean the population has gone almost completely unmonitored since 1996. Now, with your help, FFI want to change that.



By working closely with local people we can help safeguard the areas needed to protect the last surviving eastern lowland gorillas in the area between Maiko and Kahuzi-Biega National Parks in the eastern DRC.

FFI wants to protect existing gorilla families in a vulnerable – currently unprotected – area between the Maiko and Kahuzi-Biega National Parks. These families are vital to saving the remaining eastern lowland gorillas from extinction.

This gorilla protection has only become possible in recent years. Since the elections in the DRC in 2006, and the increased stability that came with them, conservation teams are starting to consolidate a series of community reserves to ensure the gorillas are fully protected.



"The Maiko and Kahuzi-Biega National Parks in the DRC are home to some of the most endangered species in Africa, including the eastern lowland gorilla. However, as human populations in the region expand so too does the risk from habitat loss. A participatory form of conservation is giving these communities a means to exist and is helping the eastern lowland gorilla and other wildlife. Time is short and I urge supporters of FFI to quickly back this vital work that is crucial to the survival of the eastern lowland gorilla."

**Sir David Attenborough OM FRS,
Fauna & Flora International vice-president**

For the species to remain genetically viable, it is crucial that the gorilla families can interbreed and are not separated by deforestation and agriculture expansion in an unprotected area. FFI knows community managed land is a sustainable way to achieve this.

To do all this FFI needs to raise £130,489.56 to protect 10,847.67 km² of forest, where the gorillas are at risk. The £130,489.56 must be raised as soon as possible so that the team at FFI have time to plan ahead. Meanwhile unprotected gorillas are dying from the threats they face every day.

The eastern lowland gorilla is on the very edge of survival. Together we can save it. Please send your gift by 14 December – at the very latest.

Fauna & Flora International (FFI) have launched an emergency appeal to raise £130,489.56 from readers that will enable them to push ahead with the protection of new Community Reserves in the Democratic Republic of Congo. This is crucial to the battle to save the Endangered eastern lowland gorilla from extinction. You can contribute by cutting the coupon below, visiting www.savegorillas.org.uk or calling 01223 431991.

How you can help save the eastern lowland gorilla

£130,489.56 is sought from readers to urgently protect a series of community nature reserves that will safeguard the gorillas in unprotected areas – where they are at risk of losing their habitat and being killed by hunters. These are a few of the items urgently needed:

- £40.10 could pay for rations for a gorilla survey team
- £129.36 could pay for fuel to run the team's off-road vehicle for a month
- £258.72 could pay for a GPS unit and batteries, to help the teams locate gorilla families in the dense rainforest
- £679.15 could pay for a satellite phone, to help the teams report and respond to emergencies
- £19,180 is also needed to fund the entire DRC conservation team for 6 months.

Any donations, large or small, will be received with thanks.

Cut the coupon below and return it with your gift to FFI, to help save the remaining 10,000 Endangered eastern lowland gorillas. Alternatively, go to www.savegorillas.org.uk or call 01223 431991. Thank you.

I want to help save the remaining 10,000 eastern lowland gorillas with a donation of £ _____

Title _____ Forename _____
Surname _____
Address _____
Postcode _____
Email _____
Phone No _____

☐ I enclose a cheque payable to Fauna & Flora International **OR**

☐ I wish to pay by credit/debit card

Type of card: Visa ☐ Amex ☐ Mastercard ☐ Maestro ☐ CAF ☐

Card No: _____ Start Date: _____

Expiry Date: _____ Issue Number (Maestro only): _____

3 digit security code: _____ (Last three digits next to the signature)

Please note: If Fauna & Flora International succeeds in raising more than £130,489.56 from this appeal, funds will be used wherever they are most needed. If you'd prefer not to be mailed ☐ emailed ☐ or telephoned ☐ please tick the appropriate box or contact us at any time.

**Please return to: Gorilla Appeal, c/o FREEPOST RRHG-GBGG-CAGG,
Fauna & Flora International, 4th Floor, Jupiter House, Station Road,
Cambridge, CB1 2JD, UK**

or go to www.FFIgorilla.org to donate online now.

Registered Charity No 1011102. Registered Company No. 2677068.

**FAUNA & FLORA
INTERNATIONAL**

**FundRaising
Standards Board**
PR-EG15BF

THE ULTIMATE CHRISTMAS

WISHLIST

MICROSOFT SURFACE PRO 4

A few short years ago, the laptop was pronounced dead: the future, declared the techno-savants, lay with tablet computers. Then the world realised that while tablets are great for web-browsing, playing games, watching movies or checking your email, they're a bit rubbish when it comes to doing any actual work. And so 'hybrids' – tablet computers with a detachable keyboard – are officially this year's must-have device.

The Surface Pro 4 is Microsoft's latest offering in the hybrid sector, and builds upon the success of the Surface Pro 3. The Type Cover detachable keyboard is now sturdier and boasts a more responsive trackpad, while the display has been enlarged to 12.3 inches. The Surface Pro 4 is available with a choice of three processors, all using Intel's state-of-the-art Skylake architecture, and with storage options ranging from 128GB to 1TB. It's being touted as the first tablet to truly rival a laptop in terms of performance – and that means you can expect it to sell by the lorryload this festive season. Buy early to avoid disappointment!

From £749 (Type Cover £110 extra),
microsoftstore.com



Tech Hub

BOOGIE DICE

Take the hard work out of board games by investing in a pair of dice that roll themselves when you click your fingers! You'll have to wait a while, though: Boogie Dice smashed their Kickstarter target but won't actually ship until March.

\$22 (£15 approx), facebook.com/theboogiedice

UNDER
£50

MATTEL VIEWMASTER VR

Virtual reality headsets are going to be all the rage in 2016, and Mattel's getting in on the act with this update of its classic Viewmaster. It works with all Google Cardboard apps, but Mattel's own apps add an augmented reality layer using the familiar physical reels.

\$30 (£20 approx),
view-master.com



SMART LETTERS

Teach your kids to read the old-fashioned way, using some cut-out wooden letters. There's a twist, though: these ones can be placed on an iPad screen and used to interact with kiddy-friendly educational apps such as *Vocabubble*, *My Words* and *Alphamonster*.

\$34 (£22 approx),
marbotic.fr

HOT THIS YEAR



HP LAPTOP

£549,
hp.com/UK



BLUETOOTH SPEAKER

\$59.99 (approx £39),
ihomeaudiointl.com



BB-8

£129.99,
sphero.com

SMARTPHONE PROJECTOR

Turn your smartphone into a home cinema projector using a cardboard box and an 8x magnifying lens. Great for watching *Carry On Camping* in your tent, or *The Cabin In The Woods* in your cabin in the woods. Actually, maybe not the latter...

£15.95, prezzybox.com



GOOGLE CHROMECAST AUDIO

If you're keen to embrace high-res audio streaming but are already heavily invested in old-fashioned hi-fi, this inexpensive dongle will enable you to wirelessly stream audio from your smartphone, tablet or laptop to your existing amplifier.

£30, google.com



DOTT SMART DOG TAG

This Bluetooth smart dog tag will keep you notified of your canine chum's movements at all times, and if Fido strays out of range, his collar can still relay his location by connecting to other Dott-enabled devices nearby. You can even have it custom-engraved for an extra \$6.

\$30 (£20 approx), dottdogtag.com





FUJIFILM INSTAX MINI 70

The latest addition to Fujifilm's Instax range of instant cameras features unashamedly nostalgic styling and is available in a choice of three colours. It also boasts auto exposure control and a 'selfie mirror' so you can check your duck face is looking proper peng before you shoot, or something. £99.99, fujifilm.com



£50 - £100

OLLOCLIP 4-IN-1 LENS

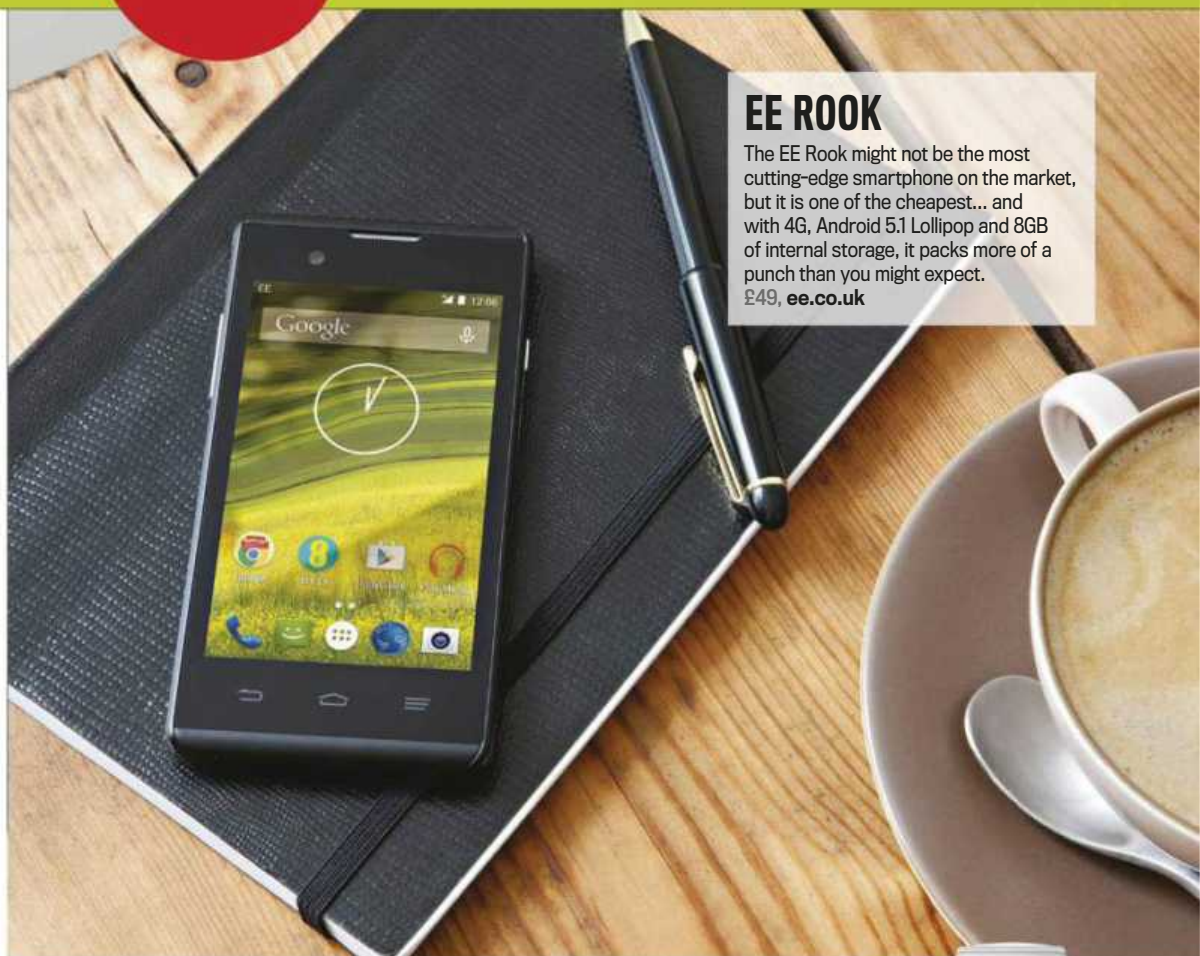
Ollclip makes many different lenses that will boost the photo capabilities of your smartphone or tablet. This 4-in-1 model for iPhone 6/6S offers fisheye, wide-angle, 10x macro and 15x macro options.

£69.99, olloclip.com



EE ROOK

The EE Rook might not be the most cutting-edge smartphone on the market, but it is one of the cheapest... and with 4G, Android 5.1 Lollipop and 8GB of internal storage, it packs more of a punch than you might expect. £49, ee.co.uk



LG WATCH URBANE 2

Price TBC,
lg.com/uk



MICROSOFT BAND 2

£199.99,
microsoft.com



**APPLE
WATCH**
From £299,
apple.com





MOS AUDIO S+

This Bluetooth speaker from Ministry Of Sound has been built with input from the sound techs that built the world famous nightclub's own sound system, and offers 15 hours of playback as well as an audio line-in for connecting non-Bluetooth devices.

£129.99, ministryofsound.com/audio



DRIFTER WATERPROOF SPEAKER

There are lots of waterproof speakers for use by sailing buffs and so on... but most involve keeping your non-waterproof phone within Bluetooth distance, somewhat defeating the object. Not so Drifter, which has its own built-in player and 16GB of storage.

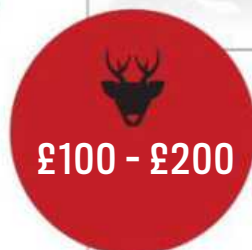
\$199 (£129 approx), getdrifter.com



GOPRO HERO 5

The latest addition to the GoPro range of action cameras offers the ability to film at 8K resolution, as well as shoot 4K Ultra HD video at 60fps for ultra-detailed slow-motion footage.

£TBC, gopro.com



LITTLEBITS GADGETS & GIZMOS

Littlebits is one of the leading suppliers of educational science toys for kids. This latest set consists of 15 electronic blocks which young 'uns can use to build 12 different electronics projects including a wireless doorbell, a remote control robot and a bubble machine.

\$200 (£130 approx), littlebits.cc



HOT THIS YEAR



YUNEEC Q500 TYPHOON

From £839.99,
yuneec.uk

DJI PHANTOM 3

£619,
dji.com



HUBSAN H111

£34.99,
hubsan.com

Tech Hub

LIGHT L16

This Android-enabled compact camera features no fewer than 16 different lenses. Every time you take a picture, it uses all 16 of them - then combines all that information into one 52MP shot whose focus, exposure, depth of field etc can be adjusted, in Lytro-like fashion, after the picture's been taken.

\$1,699 (\$1,100 approx), light.com



£200+

HP 34-INCH ENVY CURVED ALL-IN-ONE

If this curved, 34-inch all-in-one PC doesn't elicit a gasp of envy from all your friends, you clearly haven't got any friends. Comes with Windows 10, six B&O speakers and a wide range of CPU, RAM and storage options.

\$1,800 (£1,170 approx),

hp.com/envy



DYSON PURE HOT+ COOL

Combining an air filter, heater and bladeless fan in one stylish unit, this latest innovation from Dyson must surely be the last word in domestic climate control - until Dyson comes up with another one, anyway. You'll have to send off to Japan to get one, mind you...

¥74,300 (£400 approx), dyson.co.uk

LENOVO IDEAPAD MIIX 700

This Lenovo hybrid was designed as a more affordable rival to the Surface Pro 3, and has proved something of a surprise hit thanks to its 12-inch display, Core M7 chip and 8GB of RAM.

\$699 (£455 approx), lenovo.com



ATOMIC FLOYD SUPERDARTS TITANIUM

If these look familiar, it's because we raved about them when they featured in our 'tough earphones' Ultimate Test earlier this year. With great sound and Hummer-like build, they're also the most comfortable earbuds we've ever tested - making that hefty price tag actually look pretty reasonable!

£249, atomicfloyd.com



PONO

\$399 (£260 approx),
ponomusic.com



ASTELL & KERN AK380

£3,000,
astellakern.com

PIONEER XDP-100R

£499,
pioneerelectronics.com



THE EARTH'S CLIMATE IS CHANGING

BY KATE RAVILIOUS

Global temperatures have risen and fallen repeatedly during our planet's long history, so should the recent rises be any cause for alarm? And are we really to blame for them?

O

NCE UPON A time, palm trees flourished in the Arctic and crocodiles basked on Alaskan beaches. There was no ice at either of the poles, and Earth's average temperature was nearly 23°C (today's average is around 14.6°C). This was our planet 56 million years ago, a time known as the 'Paleocene-Eocene thermal maximum'. For Earth, global warming is nothing new.

Today, the Earth is warming once more. Since 1880, the average global temperature has risen by 0.8°C, and in recent times warming has really escalated, with 10 of the warmest years occurring since 2003, and 2014 being the warmest year on record. As our planet has become hotter, our oceans have soaked up the heat, making surface waters around 1°C warmer than they were 140 years ago. When water warms it expands: the sea level has risen 17cm over the last century. Already low-lying Pacific islands, such as the Polynesian island of Tuvalu, are struggling with frequent floods.

Meanwhile on land, glaciers and ice sheets are melting all over the world. Satellite measurements reveal that

around 400 billion tonnes of glacier ice has gone since 1994. In Tanzania the snowy summit of Mt Kilimanjaro is shrinking, and estimates suggest the glacier may disappear completely by 2030. One gruesome side effect is the number of dead bodies emerging from under the ice – from victims of mountaineering accidents in decades past, to recent plane-crash victims and, in South America, Inca children who were sacrificed 500 years ago.

Sea ice is also disappearing, with satellite observations showing that

the area covered by Arctic sea ice is now shrinking by more than 10 per cent per decade. In recent years, ships other than icebreakers have been able to glide through the fabled 'Northwest passage' with ease.

WHAT'S GOING ON?

These measurements confirm that our planet is warming, but what's pushing temperatures up? During Earth's last major warming phase – the Paleocene-Eocene thermal maximum – carbon dioxide (CO₂) was the culprit. The splitting of the Pangaea supercontinent triggered that warming: as the land tore apart, volcanoes sprung up in the cracks, frequently erupting and belching out carbon dioxide.

Carbon dioxide is a greenhouse gas, as is water vapour, methane, nitrous oxide and ozone. These gases trap heat in the atmosphere and keep Earth warmer than it would be otherwise by absorbing heat coming from the Earth's surface. On some planets, like Venus, the greenhouse effect is massive. There the dense, carbon dioxide-rich atmosphere elevates surface temperatures up to a blistering 460°C. In contrast,



People on a flooded street in Tuvalu, where rising sea levels are already causing problems

> IN A NUTSHELL

Earth's climate is determined by the interaction of a bewildering number of different processes. But as our ability to measure and analyse the climate has improved, it's become increasingly clear that man-made carbon emissions are driving rising temperatures.

→ planets without greenhouse gases, like Mercury, have no way of preventing heat escaping at night so they experience huge swings in temperature: Mercury goes from 400°C in the day to -170°C at night. Without greenhouse gases, Earth's average surface temperature would be below freezing but with vast variation between day and night.

The greenhouse effect has helped to keep Earth habitable, but the geological record reveals that even small changes in the proportions of greenhouse gases can have a big effect on climate. During the build-up to the Paleocene-Eocene thermal maximum,

volcanoes are thought to have pumped around five billion tonnes of CO₂ into the atmosphere, resulting in a warming of around 6°C over a period of 20,000 years, with seemingly no ill consequences. So why is everyone fretting about the recent 0.8°C rise in average global temperature?

The answer is the speed of change. In the years leading up to the Paleocene-Eocene thermal maximum, the planet warmed by around 0.025°C every century. Today Earth's thermostat is being cranked up by around 1°C every century – that's 40 times faster. Meanwhile, measurements show that during the 21st Century the burning of

fossil fuels released around 35 billion tonnes of carbon dioxide into the atmosphere every year. Volcanoes, by contrast, release just 0.2 billion tonnes per year.

The link between burning fossil fuels and altering Earth's climate was predicted over a century ago. In 1896, Swedish scientist Svante Arrhenius realised that the Industrial Revolution was altering the chemistry of Earth's atmosphere and calculated how future emissions of carbon dioxide might alter the surface temperature on Earth. Arrhenius showed that burning coal would significantly increase the levels of carbon dioxide in the atmosphere,

THE KEY EXPERIMENT

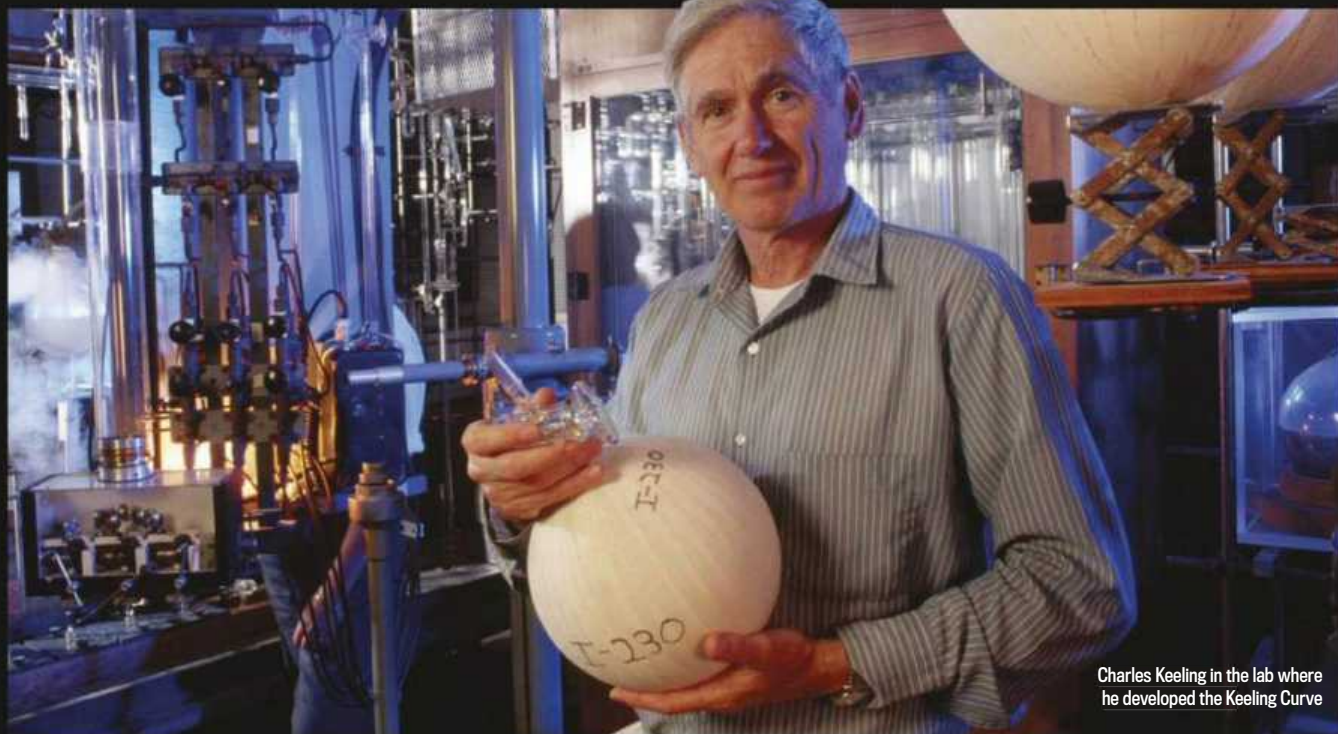
Nearly 60 years ago, US scientist Charles Keeling began monitoring atmospheric carbon levels in Hawaii, providing the foundation for our understanding of the problem today

IN 1958, AMERICAN chemist and oceanographer Charles Keeling began measuring atmospheric carbon dioxide concentrations at the remote Mauna Loa Observatory in Hawaii. He chose this location because it was far from the influence of smoky chimneys. By taking measurements high on the mountain, in the ocean breeze, he could ensure he was sampling average concentrations over a wide area. Initial measurements

revealed a strong seasonal cycle, with levels dipping every summer as plants absorbed carbon dioxide. But by 1961, his results showed that atmospheric CO₂ levels were rising steadily.

At first, his findings failed to attract much attention and he struggled to find funding. Luckily, he scraped together enough money to keep the experiment going. Today there are approximately 100 locations around the globe measuring

atmospheric carbon dioxide, but Keeling's long-running experiment provides the most convincing proof that human activities are increasing carbon dioxide levels. The Keeling Curve shows that average carbon dioxide concentration was 315 parts per million by volume (ppmv) in 1958, and that it peaked at 401ppmv in spring 2014 – higher than at any other point in the past 800,000 years.



Charles Keeling in the lab where he developed the Keeling Curve

and estimated that a doubling of carbon dioxide would cause the temperature to rise by around 4°C – not far off the predictions made by modern climate models. Unlike today's scientists, though, Arrhenius concluded that the resultant warming would be a good thing, preventing the world from entering a new ice age and helping crops to grow to feed the rapidly increasing population.


COMPETING INFLUENCES

Predicting global warming was fairly straightforward, but actually measuring it hasn't been quite as easy. That's because Earth's climate is influenced by many factors, including cloud, snow and ice cover, volcanic activity, ocean temperature, cosmic ray flux, distance from the Sun and sunspot cycles. Constant changes in all of these factors keep Earth's climate yo-yoing up and down.

For example, after Mount Pinatubo in the Philippines erupted in 1991, the dimming caused by the ash cloud resulted in global temperatures dropping by 0.4°C the following year. Meanwhile, the periodic warming in the western Pacific Ocean known as El Niño created havoc in 1997, bringing droughts to some parts of the world and extreme rainfall to others. Teasing out the impact of rising carbon dioxide from natural highs and lows of climate has proved to be a herculean task – but separate studies of global temperatures and CO₂ suggest there is a relationship between them.

Back in 1938 a British engineer and amateur climatologist called Guy Callendar gathered temperature measurements from 147 weather stations scattered around the globe, to try and work out whether the world was indeed warming. Although he had no data from the Arctic, Antarctic or over the oceans, he showed that the planet had warmed by around 0.3°C over the previous 500 years.

Callendar's calculations reignited the debate over whether CO₂ emissions could change Earth's climate. But his evidence failed to convince people, partly because global warming ground to a halt around 1940 and temperatures plateaued until the mid-1970s. Furthermore, most people believed the oceans would mop up most of our excess carbon emissions.

This relaxed attitude to carbon emissions began to change in 1957, 

CAST OF CHARACTERS

Five innovative scientists who helped us understand how Earth's climate works



Joseph Fourier

The 'greenhouse effect', as it's now known, was discovered in 1824 by French physicist, Joseph Fourier. He calculated that the Earth should be colder than it actually was if it was only warmed by solar radiation.



Svante Arrhenius

In 1896 this Swedish scientist realised that the burning of coal would increase carbon dioxide and enhance the Earth's greenhouse effect. He estimated that a doubling of carbon dioxide would lead to a temperature rise of around 4°C – not far off the predictions made by modern climate models.



Roger Revelle (pictured) and Hans Suess

Together, these US scientists overturned previous assumptions and showed that the oceans would not be able to absorb all of the additional carbon dioxide that burning fossil fuels was adding to Earth's atmosphere.



James Lovelock

An independent British scientist who developed Gaia theory in the 1960s. This is the idea that Earth is a living system, and that life on Earth interacts with its surroundings to keep the planet habitable. Crucially, the theory has led to the prediction of 'tipping points' in Earth's climate.



James Hansen

Outspoken US scientist and climate activist who produced the first climate model prediction in 1988. In the same year, Hansen gave a testimony before the US Congress saying that it was "99 per cent certain that the warming trend was not a natural variation but was caused by a build-up of CO₂ and other artificial gases in the atmosphere."

TIMELINE

A brief history of climate change and carbon emissions, from the steam engine to Al Gore



British ironmonger Thomas Newcomen invents a steam engine for pumping water out of tin and coal mines. This is the first step on the road to the Industrial Revolution.

1712

1886

German engineer Karl Benz is granted a patent for his first automobile. By 1888 his 'Motorwagens' are on sale to the public; the motoring era has begun.



1961

British engineer and amateur climatologist Guy Callendar shows that the planet has warmed by around 0.3°C over the previous 50 years.



1938



American scientist Charles Keeling shows that levels of carbon dioxide in Earth's atmosphere are rising steadily.

2007

The IPCC's 4th Assessment Report states: "It is extremely likely (over 95 per cent) that human activities have exerted a substantial net warming influence on climate since 1750."



2007

The Nobel Prize for Peace is awarded jointly to the IPCC and former US Vice President Al Gore (pictured), for their efforts to obtain and disseminate information about the climate challenge.



after US scientists Roger Revelle and Hans Suess managed to track the lifetime of carbon molecules in the ocean using radiocarbon dating. They showed that most carbon dioxide absorbed by the ocean evaporated back into the atmosphere after a few years.

Soon after, another US scientist, Charles Keeling, began measuring atmospheric CO₂ concentrations at the remote Mauna Loa Observatory in Hawaii in 1958. His initial measurements revealed a strong seasonal cycle, with carbon dioxide levels dipping every summer as plants absorbed the gas. But by 1961 he was also able to show that carbon dioxide levels were steadily rising.

Today, Keeling's long-running experiment provides the most convincing proof that human activities are increasing carbon dioxide levels. The Keeling Curve shows that in 1958, the average carbon dioxide concentration was 315 parts per million by volume (ppmv), and that it peaked at 401ppmv in spring 2014. Meanwhile, measurements of gas trapped in air bubbles in polar ice cores show that the average concentration of CO₂ during the last 10,000 years has been between 275 and 285ppmv, and it's only since the 19th Century that levels began to rise sharply. This rise in atmospheric carbon dioxide is also reflected in the oceans, where the dissolving of carbon dioxide has increased acidity of surface waters by around a third since the start of the Industrial Revolution.

UNNATURAL CHANGE

But rising carbon dioxide alone didn't prove that the climate is changing, or that man was responsible – stronger evidence was required. By the mid-1970s global temperature began to rise again, after a 35-year hiatus. It's now believed that temperatures were suppressed during this period by the particles and soot released by burning fossil fuels, which reflected more solar radiation back into space.

During the 1980s there was still much scepticism that global warming was real, but there were some strong dissenting voices. In 1988 US climatologist James Hansen produced the first climate model prediction and, in the same year, gave a testimony before the United States Congress saying that it was "99 per cent certain that the warming trend was not a

NEED TO KNOW

A handy glossary of terms for understanding climate change

1 GREENHOUSE GAS

A gas that traps heat in the atmosphere and keeps Earth warmer than it would otherwise be, by absorbing heat coming from the Earth's surface. Examples include methane, ozone and carbon dioxide.

3 SUPERCONTINENT

A vast landmass made up of most of Earth's continental blocks. Supercontinents have formed at least seven times in Earth's history, the most recent being the supercontinent of Pangaea, which started to break up around 180 million years ago.

4 RADIOCARBON DATING

A means of calculating the age of anything containing carbon by assessing the amount of radioactive decay, developed in the late 1940s.

5 TIPPING POINT

An abrupt change in global climate from one stable state to another. Some tipping points are thought to be irreversible, comparable to tipping over a glass of wine: standing the glass back up won't return the wine back to the glass.

natural variation but was caused by a build-up of carbon dioxide and other artificial gases in the atmosphere." Some politicians, including British Prime Minister Margaret Thatcher (who had a degree in chemistry), were convinced by the threat. In a speech to the United Nations in 1989, Thatcher said: "We are seeing a vast increase in the amount of carbon dioxide reaching the atmosphere. The result is that change in future is likely to be more fundamental and more widespread than anything we have known hitherto." At the same time, she called for a global treaty on climate change.

But many didn't trust these predictions, and insisted that the changes in climate could just be part of natural variability. In 1988 the Intergovernmental Panel on Climate Change (IPCC) was formed to monitor and assess the evidence



British economist Sir Nicholas Stern, speaking at a press conference on his report 'The Economics of Climate Change' in 2006. The report highlighted the importance of dealing with climate change sooner rather than later

that the climate was changing. It took until 2007 for the IPCC to gather enough evidence to state conclusively that it was exceedingly unlikely – less than a 5 per cent chance – that natural variations were causing the changes we were seeing. In other words, after running thousands of climate simulations of the last century, scientists had found that today's climate only emerges naturally in five out of every hundred runs. In their 2007 Fourth Assessment Report, the IPCC stated: "It is extremely likely (over 95 per cent) that human activities have exerted a substantial net warming influence on climate since 1750."

Although not 100 per cent proven, the links between human activity and global warming are now compelling enough for economists to sit up and take notice. In 2006 British government economist Nicholas Stern published a review which concluded that, if left unchecked, the cost of climate change will be equivalent to losing at least 5 per cent of global gross domestic product each year. By contrast, his calculations suggest that curbing climate change would cost around 1 per cent of global gross domestic product. Not everyone agrees with Stern's figures, but most accept that climate change will be cheaper to tackle now rather than later.

Today, the major concern is how much climate change we're committed to. In the 1960s James Lovelock, a British scientist, developed Gaia theory – the idea that Earth is a living system, and that life on it interacts

with its surroundings to keep the planet habitable. Gaia theory was greeted with scepticism initially, but it has gained credibility and today a number of scientists are worried about what happens when the Earth is pushed too far. Gaia theory suggests that climate change doesn't always happen smoothly and sudden leaps should be expected. We refer to these abrupt changes as 'tipping points'. For example, there is concern that if the Arctic is warmed enough it could lead to methane bubbling out of previously frozen soil. The consequences of such a huge pulse of greenhouse gas would likely occur very fast and perhaps lead to irreversible climate change.

Earth has seen extremes in climate before, from when ice stretched all the way to the equator, to when palm trees flourished in the Arctic. But never has its climate been pushed as fast as it is today. In 1957, Roger Revelle wrote: "Human beings are now carrying out a large scale geophysical experiment." Today the experiment continues, but we still have little idea of the outcome. ■

KATE RAVILIOUS is a freelance science journalist. She is based in York

DISCOVER MORE!



Listen to *Changing Climate Change* on BBC World Service from 18 November

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TO DO LIST

PLAN YOUR MONTH AHEAD WITH OUR EXPERT GUIDE

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PICK OF THE MONTH



➔ WITH THE GLOBAL population expected to reach 9.7 billion by 2050, and much of that growth happening in the poorest countries, the race is on to find new ways to feed the planet. From lab-grown meat to desert-dwelling farms, this new three-part series looks at some of the ways in which science is transforming what's on our plate.

Anchored by Dara O Briain, *Tomorrow's Food* explores the technologies that are finding their way into our farms, supermarkets, kitchens and restaurants. Michelin-starred chef Angela Hartnett reveals how 3D printing is revolutionising the food industry, and asks whether the burgers of the future will be more mealworm than meat.

Meanwhile, technology expert Dr Shini Somara has some good news for those with a sweet tooth. We might soon be able to harness the power of the miracle berry: a West African fruit that has the bizarre property of making sour foods taste sweet.

"I chewed on some lemon, and it tasted like lemonade," says Shini.

This is all down to a protein in the berry called miraculin, which binds to the taste buds and alters the perception of any subsequently eaten foods. The

idea is that this protein could be used as a natural sweetener, reducing sugar intake around the world.

"It's very expensive to grow these berries, but scientists are trying to implant the protein into tomatoes, which are much easier and cheaper to grow," says Shini.

Elsewhere in the series, greengrocer Chris Bavin looks at some of the ways in which farms are embracing the future, from those whose crops never see the light of day, to those that use robots to do the dirty work. One such robot is the 'Shrimp' – an automated farmhand that performs manual tasks such as watering, mowing and herding cows.

But if you want to see a robot in action, soon you might need to go no further than your local fast food joint. In Tokyo, Shini visits a restaurant where the food is cooked and served by automatons. Domo arigato, Mr Roboto.

JAMES LLOYD



Watch *Tomorrow's Food* on BBC One this November. Check *Radio Times* for full details

DON'T MISS!



Deadly 60

Steve Backshall gets up close and personal with snakes, crocodiles, eels and more. **p114**



Christmas Lectures

Spooked by space after *The Martian*? Kevin Fong reveals how we can cope in the cosmos. **p115**



Evolving Ourselves

According to a new book, we might still be evolving. Now take your knuckles off the floor! **p116**



WATCH

TV & ONLINE
WITH JAMES LLOYD

FROM 16 NOVEMBER

Deadly 60

Eden, 8pm

STEVE BACKSHALL GOES in search of the animals you'd least like to meet. Great white sharks, crocodiles, electric eels, charging rhinos... Steve (pictured below) gets up close and personal, travelling the world so that we can enjoy them from the safety of our sofa. Pass the popcorn.



16 NOVEMBER

Explorer: Bill Nye's Global Meltdown

National Geographic, 8pm

HOW CAN WE overcome the antipathy towards global warming? Bill Nye the Science Guy has a unique approach, exploring five stages of 'climate change grief' with his 'therapist' Dr Arnold Schwarzenegger. The journey takes him from denial to acceptance as he investigates how we can heal our ailing planet.

22 NOVEMBER

Wild Yellowstone

Nat Geo Wild, 6pm

THIS TWO-PART series follows a year in the life of the creatures that call Yellowstone home, from the red foxes and river otters that battle through the winter to the hummingbird that's fighting to protect its summertime territory of wildflowers.



2 DECEMBER

Racing Extinction

Discovery, 9pm

ACCORDING TO MANY scientists, we're currently experiencing one of the most catastrophic extinction events in our planet's history. This impassioned new film from the team behind the Oscar-winning *The Cove* shines a light on two of the major threats to endangered species: the international wildlife trade and the damage being done to the planet by us humans.



LISTEN

Atmosphere Week

BBC World Service, 14-20 November



THE UN CLIMATE Change Conference is soon taking place in Paris. In the run-up, the BBC World Service has dedicated a week of programming to the layer of gases that keeps us all alive.



Expect the latest news on vehicle emissions



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Khan Academy

iOS 7.0 or later, iPhone/iPad/iPod Touch, Android 4.1 or later, free



SALMAN KHAN BELIEVES that learning should be free to all, which is why he started educational website the Khan Academy. Now, the redesigned app allows you to learn on the go. It provides access to over 10,000 videos and explanations at all levels of experience, with science and

maths being two core disciplines covered. There are quizzes to help solidify the lessons, plus 150,000 maths exercises for those who fancy giving their number-crunching skills a workout.

Star Walk 2

iOS 7.0 or later, iPhone/iPad/iPod Touch, Android 4.0 or later, Vito Technology, £2.29/£2.02



THE BEST-SELLING app *Star Walk* has now been upgraded to include stunning animated graphics of the constellations, plus oodles more new features to feed your passion for the night sky. The augmented reality view shows the star map overlaid through your device's camera, and you can zoom right in to take a closer look at other planets in the Solar System, as well as distant galaxies and nebulae. With the 'Planets' in-app purchase for an extra 79p, you can also explore eye-popping 3D models of celestial objects such as satellites, comets and asteroids.

The Earth

iOS 7.0 or later, iPhone/iPad, Tinybop, £2.49



THIS IS A charming interactive app for children aged four and up to learn all about the inner workings of our planet. Unlike other apps aimed at this age range, the facts aren't spouted out by a cutesy cartoon character. Instead, it's all about discovery. You can trigger earthquakes, erupt volcanoes, and manipulate the forces of geology. The app is engaging, but kids will get more out of it if there's an adult playing with them to talk through what's happening.

KATE RUSSELL is a technology journalist and *Click* presenter



VISIT

EVENTS & EXHIBITIONS

WITH JHENI OSMAN

20 & 21 NOVEMBER

An Evening With The Stars

Royal Observatory Greenwich, 5:25pm-7:25pm & 6:45pm-8:45pm, £18, advanced booking essential, rmg.co.uk

QUIZ ASTRONOMERS WITH your questions and soak up the stars as you peer through the gigantic Great Equatorial Telescope.



24 NOVEMBER

Think Space Lecture

Royal Observatory Greenwich, 7pm-8:30pm, £6, rmg.co.uk

AT THIS LECTURE, find out about the latest research in astrophysics.

24 NOVEMBER

Crack The Case

Museum of London, 7pm-10pm, £36, museumoflondon.org.uk

TRY OUT MODERN modern crime-prevention techniques at this event, which also takes place on 16 December. But don't kid yourself that you're ready to fill Cumberbatch's shoes just yet.



26 NOVEMBER

Crucial Interventions

Wellcome Collection, London, 7pm-8pm, free, wellcomecollection.org

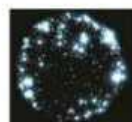
THE STUNTS SEEN on *Jackass* are nothing compared to the pain inflicted by 19th-Century surgical implements. Join historian Richard Barnett and see some unnerving material up close. Ouch!

28 NOVEMBER

Saturday Studio: Game-Making Workshop

Wellcome Collection, London, 2pm-5pm, free, wellcomecollection.org

AVID GAMERS WILL love this drop-in session, and will even have the chance to design their own simple game.

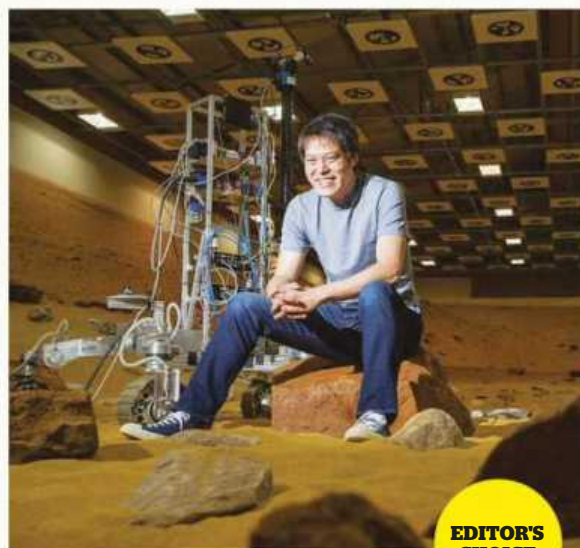


3 DECEMBER

Big Bang Data

Somerset House, London, £12.50, somersethouse.org.uk

AT THIS EXHIBITION, which runs until February 2016, discover a diverse collection of data-driven artworks.



EDITOR'S CHOICE

18, 19 & 22 DECEMBER

Royal Institution Christmas Lectures: How To Survive In Space

Royal Institution, London, 6.30pm-10.30pm, £12, rigb.org



IN THE MOVIE *The Martian*, Matt Damon could have done with a few tips from Kevin Fong (pictured above) on how to survive in space. If you can't get your hands on tickets to see Fong live in action at this year's Christmas Lectures, why not go behind the scenes instead? Sneak into lecture rehearsals, then take a peek in the workshop to find out how the demonstrations come to life. The Christmas lectures will be broadcast on BBC Four over the festive period – check the *Radio Times* for more details.

8 DECEMBER

The Search For Life In The Universe

Royal Astronomical Society, London, 1pm-2pm & 6pm-7pm, free, ras.org.uk

AT THIS TALK, discover how we use 'extreme' life forms on Earth to predict what life might be like in the cosmos.

10 DECEMBER

Christmas Lecture

Royal Observatory Greenwich, London, 7pm-8:30pm, £8, rmg.co.uk

FIND OUT WHY comet 67P/Churyumov-Gerasimenko is nicknamed 'the rubber duck' at this talk by TV presenter Dr Monica Grady.



UNTIL 2 FEBRUARY

Hubble At 25

Life Science Centre, Newcastle, life.org.uk

THE HUBBLE SPACE Telescope completely changed the way we see our Universe. Celebrate 25 years of its incredible images at this planetarium show, which is included in the centre's admission price.



READ

THE LATEST SCIENCE BOOKS REVIEWED

Hardback Paperback

Evolving Ourselves:

Juan Enriquez and Steve Gullans

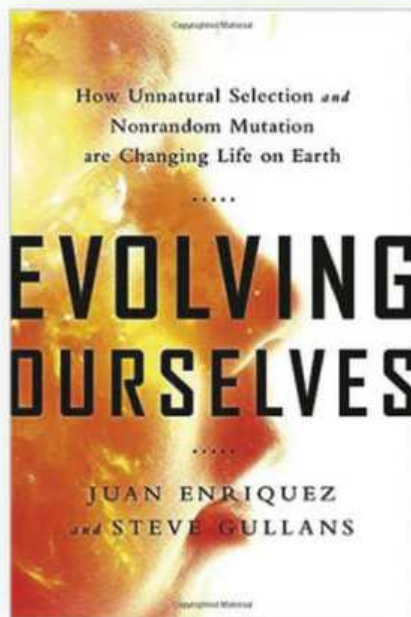
Oneworld £12.99

ARE HUMANS STILL evolving? Given our ingenuity and the myriad ways we've found to outwit the whittling force of natural selection, it can sometimes feel like the answer is 'no'. But, according to future-thinking venture capitalists Juan Enriquez and Steve Gullans, human evolution is not just still occurring: it's taking place faster than ever before, and we're the reason why.

"Over the past century, as our species grew by billions, concentrated in cities, smartened, and domesticated itself and its surroundings, we became the fundamental driver of what lives and dies," they write. Through this 'unnatural selection', Enriquez and Gullans claim that we've ended up evolving ourselves.

We have certainly changed a lot. Over several enthralling chapters, the authors illustrate the dramatic extent of our power to transform. An area equivalent to the whole of South America is under cultivation to provide food for ourselves and our animals. We are in the midst of an autism epidemic. Allergies are flaring up as never before. Global obesity is ballooning, fed by "tidal waves of nachos and pizza". We are moving into cities. "It would be surprising if such massive changes did not lead to rapid adaptation and ultimately speciation," they write.

"Evolution is not just still occurring: it's taking place faster than ever before, and we're the reason why"



In addition to unnatural selection, Enriquez and Gullans suggest another force that's driving human evolution. Our ability to create 'non-random mutations', tinkering with the very material of inheritance, must be taking the human genome in a new direction, they assert.

The authors entertain some wacky but plausible future scenarios, predicting that we'll soon be editing our genomes and wiring up our brains to computers. They also veer into the realm of science fiction, anticipating a world in which we'll be cloning ourselves and transplanting emotions, memory and consciousness into these brave new brains.

All of this makes for fascinating reading, but Enriquez and Gullans seem to be living in some kind of magic scientific bubble, free from the messy influence of the rest of human society. Sure, we are changing ourselves and our planet in terrifying, fabulous ways. But change is a far cry from adaptation and speciation. Only time (and a dose of good old Darwinian natural selection) will tell whether any of this 'unnatural selection' or 'non-random mutation' amounts to anything approximating evolution at all.



HENRY NICHOLLS is a freelance science writer and BBC radio presenter

MEET THE AUTHOR



Steve Gullans

What do you mean by the term 'unnatural selection'?

We use this term simply as a contrast to the natural world, to describe the human-created changes that now dominate the planet.

Where do we see this happening?

The animals and plants that survive in cities did not exist in their current state in Darwin's time. Our pets would not survive in the savannahs of Africa – we've created many breeds that are not part of the natural world. In humans, we've seen increases in intelligence, height and other traits over the past 50 years. Darwin's theory is generally applied over long periods of time, but scientists are finding that evolutionary change can occur quickly, over a few generations.

What's the most remarkable way in which humans are changing?

I think it's the way our diets have changed today compared to 150 years ago. We now know that the microbes in our gut are very responsive to the food we eat, which is nothing like the primitive food that our bodies learnt to accommodate. These bacteria make hormones and vitamins for our hearts and brains, and studies show that what you eat is having a much longer-term impact than you appreciate, being passed on to your children through signatures in your DNA.

Do you think humans will eventually evolve into separate species?

We already see people break up into different social structures. So when changing a trait is as easy as getting a tattoo, you will find people who will experiment. We might not call it a new species, but self-segregation of people with different traits is inevitable given the technologies we're looking at in the future.



Thing Explainer: Complicated Stuff In Simple Words

Randall Munroe

John Murray £16.99

STUFF IN THE Earth we can burn (oil), big tiny thing hitter (Large Hadron Collider), and bags of water you are made of (cells), are some of the things Randall Munroe explains with blueprints and 1,000 of the most common English words.

Munroe once worked for NASA and now draws cartoons for the website xkcd. He admits to spending a lifetime worrying about sounding stupid. Using big words has helped him feel better. In this book, he wanted to write about 'cool ideas in new ways', without using big words.

To explain biological cells, Munroe uses a smart picture with parts dumbly labelled 'strange boxes', 'bags of death water', 'empty pockets', 'things that make you sick' etc. Such contrived simplicity fails to tell us the function of cells as tiny chemical factories. A chart called 'the pieces everything is made of' is the Periodic Table. Explaining 118 elements in terms of 'metal we add to other metals', 'rock that makes glass blue', 'the stuff teeth are made of' is certainly new. It is not cool.

If science is not your bag, *Thing Explainer* can mislead you and make you feel stupid. If it is, the book might make you feel cross. Nice idea. Smart pictures. Dumb words.



CHRISTINE EVANS-PUGHE is a freelance science and technology journalist



Hamburgers In Paradise: The Stories Behind The Food We Eat

Louise O Fresco

Princeton University Press £27.95

"THE HAMBURGERIZATION OF the world is a fact," states Louise Fresco. According to Fresco, the hamburger symbolises a global aspiration for a "Western, free, and carefree way of life". It also represents the dangers of excess and the shift to high consumption of animal proteins.

Hamburgers In Paradise covers topics from sustainable food production to biotechnology. Fresco sets out a 'Paradise Theory' to explain why we have a complex relationship with food, seeking abundance yet longing for a lost 'idyllic' way of life.

I was interested to learn that as an occasional meat-eater I am a 'flexitarian'. I then felt quite smug, as Fresco calls for a reduction in meat consumption, driven by concerns for the environment, animal welfare and public health.

Fresco's ideas are interesting, yet her verbose text can be frustrating. One particular phrase jumps out: "The words 'Dinner's ready' denote a state of mind determined by the topography of the table". Put simply, where you sit in relation to your dining companions affects your social interactions. While the full text may prove indigestible, this book has plenty of nuggets to nibble on.



EMMA DAVIES is a freelance writer with a background in chemistry and food science



EDITOR'S CHOICE

Atmosphere Of Hope: Searching For Solution To The Climate Crisis

Tim Flannery

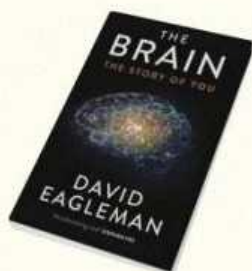
Penguin £6.99

SCIENCE WRITERS DON'T come much better than Tim Flannery. After *The Weather Makers*, his lucid study of climate change published a decade ago, Richard Branson asked him to help judge a \$25m award to find a way of removing a billion tonnes of carbon dioxide (CO₂) from the atmosphere. Nobody has won yet, but the ambitions of the 11 finalists form the heart of this dose of climate optimism.

Giant air conditioners, powered by wind, could turn the atmosphere's CO₂ into dry ice over the frozen wastes of Antarctica. Or we could give nature a helping hand by creating seaweed forests across the world's oceans. The holy grail might be combining wood-burning power stations with chemical capture of their emissions. Provided you plant new trees, the result would be an energy industry that generates electricity by sucking CO₂ out of the air. Such ideas may sound mad. But Flannery says they "have fundamentally altered my perception about how we might respond to the climate crisis". The tools to avoid climate disaster exist, he says. "We can do it."



FRED PEARCE is a science writer whose latest book is *The New Wild*



The Brain: The Story Of You

David Eagleman

Canongate £20

DAVID EAGLEMAN'S BOOK *The Brain: The Story Of You* is an informed, digestible travelogue about the territory between brain and mind. Neuroscientist Eagleman covers the ground efficiently – how the brain is 'wired' to further our chances of survival; how baby brains develop and teenage ones erupt; the weird quirks of human memory and the strange processes that underlie the apparently simple act of perception. He visits consciousness and raises (then ducks) the thorny question of free will, then strides on to cover the social brain, empathy and a possible future in which the mind blends seamlessly with digital technology.

Eagleman outlines fascinating stories and studies. There is the experience of Mike, for example, who gained sight after 40 years of blindness, but still prefers to ski blind.

There is something disappointing about this book, though. Eagleman has a rare ability to combine science with literary panache, but you don't see much of that talent here. If you want Eagleman at his best, then pick up a copy of *Sum* – his brilliant collection of short stories.



RITA CARTER is a lecturer, writer and broadcaster who specialises in the brain

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Newly invented, this tractor beam magnet contains a number of magnets in a special arrangement. The special arrangement creates a unique magnetic field that can hold another magnet a fixed distance away.



This is a Hero Steam turbine. Syringe in some water. Fill the burner with methylated spirits and light it. Moments later you have a steam turbine running. Two tiny jets of steam coming out of the side of the brass ball spins it up to 2500rpm.



These are highly polished solid metal flip over tops. They have a chrome like finish and are excellently machined. Simply spin it as normal and watch it suddenly flip over and then continue to spin upside-down.



Ferrofluid is a runny fluid that is magnetic. Hold a magnet to it and watch how it reacts. Some of the shapes you can create are mesmerizing.

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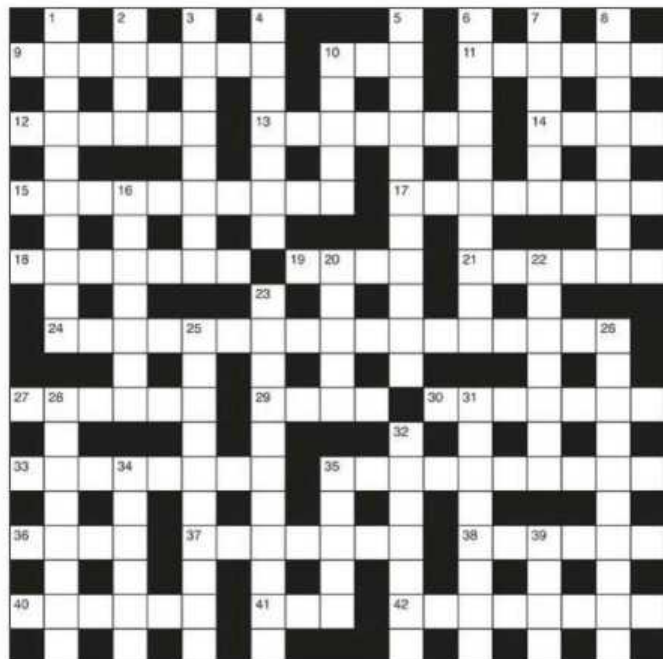
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FOCUS CROSSWORD No 184

More online Solve puzzles from BBC *Only Connect* hosted by Victoria Coren Mitchell at bbc.in/1vCOzuY



ACROSS

- 9 Processing speed makes concert a failure (8)
- 10 Betting on a spring (3)
- 11 I must turn, following left indicator (6)
- 12 Constructing a path gets husband an ulceration (6)
- 13 Lovingly have a sherry (7)
- 14 The bird in the other nest (4)
- 15 Cultivator finds margins too contrived (10)
- 17 Paint bird with performing lions (8)
- 18 Fellow has one party, say, in a kilt (7)
- 19 Reportedly obstruct some countries (4)
- 21 University students have time shortfall (6)
- 24 Part of the extent of time (6-11)
- 27 Traces out a wheel (6)
- 29 Spots cane construction (4)
- 30 Join rugby player in getting a poison (7)
- 33 Article to ruin, other than an imaginary flower (8)
- 35 Feature enamel design around tree (10)
- 36 The burden we bear (4)
- 37 Every artist contained energy and pain (7)
- 38 Way to get colour out of rock (6)
- 40 Dreadful loser has time for some alcohol (6)
- 41 Your nasturtiums have a vase (3)
- 42 In true style - negative particle (8)

DOWN

- 1 Monster's joint breaking off grip (10)
- 2 Loud performance, that's true (4)
- 3 A lab reconstructed heart of a fish (8)
- 4 A quiet laugh at soldier with a dietary problem (7)
- 5 Steaming oven - spectra vary (11)
- 6 Singer and copper join musicians' group and left one in the clouds (10)
- 7 Underline anxiety (6)
- 8 Native peach is new in courtyard, only no good (8)
- 10 Points out the nose (5)
- 16 Roman poet cut out of tube (7)
- 20 Useless thing to find in a G&T (5)
- 22 In all, no different to a woollen product (7)
- 23 A pious hoard worked like a placebo (11)
- 25 Volunteers managed to inform on a routine (10)
- 26 Providing milk and money after castle collapsed (10)
- 28 Gathered friend takes in silver first (8)
- 31 Hope is up about old horse (8)
- 32 Deduce absence of blaze (7)
- 34 Have recourse to a holiday venue (6)
- 35 Protein produces endless filth at home (5)
- 39 Starts to make a riverbed, like sedimentary rock (4)

SOLUTION TO CROSSWORD No 181

Malcolm Wyatt, Philip Glendinning, Hally Hardie, Ron Bridges and Susan Wilton each solved issue 285's puzzle and receive a copy of *Science But Not As We Know It* (Dorling Kindersley, £9.99).



WIN! THE HUNT

The first five correct solutions drawn will each win a copy of *The Hunt* (BBC, £18.99). Entries must be received by 5pm on 10 December 2015. See below for more details.



YOUR DETAILS

NAME _____

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Post entries to BBC Focus Magazine, December 2015 Crossword, PO Box 501, Leicester, LE94 0AA or email a scan of the completed crossword or a list of answers to december2015@focuscomps.co.uk by 5pm on 10 December 2015. Entrants must supply name, address and phone number. Immediate Media, publisher of BBC Focus Magazine, may contact you with details of our products and services or to undertake research. Please write 'Do Not Contact' on your email or postal entry if you do not want to receive such information by post or phone. Please write your email address on your postal entry if you would like to receive such information by email.

TERMS & CONDITIONS

Entrants must be UK residents (inc Channel Islands) aged 18 or over. Immediate Media employees are not eligible to enter. By entering participants agree to be bound by these terms and conditions and that their name and county may be released if they win. Only one entry permitted per person. No responsibility is accepted for lost, delayed, ineligible or fraudulent entries. Entries received after the closing date will not be considered. Immediate Media (publisher of BBC Focus Magazine) will only ever use personal details for the purposes of administering this competition unless you permit

otherwise. Read more about the Immediate Privacy Policy at www.immediatemediaco.uk/privacy-policy. The winning entrants will be the first correct entries drawn at random after the closing time. The prize and number of winners will be as shown above. The winners will be notified within 30 days of the closing date by post. Immediate Media's decision is final and no further correspondence relating to the competition will be entered into. If the winner cannot be contacted within one month of the closing date, Immediate Media reserves the right to offer the prize to a runner-up.

MY LIFE SCIENTIFIC

UTA FRITH

Emeritus Professor of Cognitive Development at University College London



At school in Germany, I was considered better at languages than I was at science. I studied history of art at university but ended up taking a psychology course. It made me realise, for the first time, that it was possible to study and quantify abstract mental concepts. Psychology seemed to offer the chance to discover new things.

I first came to London because all the psychology books were in English and I needed to learn the language. I fell in love with English life and culture – the museums, the science, the social life – and fell totally in love once I met my very English husband, Chris. He's a neuroscientist.

I've always been interested in autism and dyslexia. In the 60s, we were completely ignorant about these conditions. Parents were blamed: they were cold or they hadn't read enough with their children. I talked to parents and it struck me how readily they accepted blame. If it was their fault it meant there was something more they could do to help their children. It was the ultimate in parental love. I began to realise that these conditions are neurological; they have a basis in nature and are not caused by lack of nurture. It's still a controversial viewpoint but it's one that I stand by and am proud of. I hope it helps people.

The issue of gender bias in science is really important to me. I chair the Diversity Committee at the Royal Society and have founded informal networks like 'Science and Shopping' and 'UCL Women,' where high-flying, hard-working women who juggle family and career

can talk to each other and have fun. We have lunches, do wine tastings... the shopping angle never really took off.

People think I'm more empathic than I really am. I'm more detached than people realise. Maybe that's a scientific stance. I'm also very critical of myself. I'd like to be more altruistic, to fight more for injustice, but I think you have to be quite political to do that and I'm not a political person.

If I wasn't a scientist I'd be a writer or an art historian. I like going to museums and collecting things like Persian rugs, Chinese porcelain, paintings and etchings. I don't have a bucket list of things I'd like to do, but I do have a huge list of things I'm grateful I don't have to do. I would have hated to go mountaineering, horse riding or camping.

I'm working on a graphic novel with my husband and my son, Alex. Alex is a children's science book writer. The book is about what makes us social and it's going to feature both me and my husband, but in pictures. We hope to have a large part of it ready in time for our 50th wedding anniversary next year. ■



DISCOVER MORE!

To listen to an episode of *The Life Scientific* with Uta Frith, visit bbc.in/MwJnBJ



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